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Project No. 5331 (10) Name: Ecology of Sagebrush Control

Job Nos. V-1.2 and V-1.5 Title: Effects of sagebrush control treatments on vegetation and on soil moisture.

Period Covered: July 1, 1974 through June 30, 1975

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INTRODUCTION

Included in this segment of the W-105-R-10 report are the results of the "Effects of treatments on soil moisture" and "Effects of treatments on vegetation" studies.

The locations of study areas where both studies were conducted, and descriptions and locations of treatments are included in this common introduction. Locations of study areas, treated areas, and soil moisture sampling sites are shown in Figures A, B, C, D, and E.

Treatment Methods

Four areas in the Yellow Water Triangle and one in the Missouri Breaks were sprayed with 2,4-D (Table A). The Yellow Water Triangle areas were sprayed June 19-21, 1968 and the Missouri Breaks plot was sprayed in mid-May 1972 using fixed-wing aircraft.

Table A. Spray Treatment Data.

Area	Treatment	2,4-D (AMOCO) Formulation (per acre)	Amount Treated	Percent dead sagebrush after treatment[1]
Winnett	Total kill	2 lbs./6 gal. H_2O isooctyl ester[2]	480 acres	95 +
	Strip spray	2 lbs./6 gal. H_2O isooctyl ester	400 acres[3]	95 +
King	Total kill	2 lbs./6 gal. H_2O isooctyl ester	229 acres	99 +
Sibbert	Partial kill	1 lb./6 gal. H_2O dimethylamine salt[4]	253 acres	45
Iverson	Partial kill	1 lb./6 gal. H_2O dimethylamine salt	317 acres	59
	Strip spray	2 lbs./6 gal. H_2O dimethylamine salt	320 acres[3]	0-90
Missouri Breaks	Total kill	2 lbs./3 gal. diesel low volatile ester	320 acres	99 +

[1] On the basis of canopy coverage of dead vs. live sagebrush. Determined one year after treatment.

[2] 41.2 percent acid equivalent.

[3] The total area including the 100 foot wide leave strips.

[4] 46.3 percent acid equivalent.

Grazing patterns following treatment varied with different study areas. Table B shows livestock use before and after spray treatments.

Table B. Livestock Use on Treatment Areas.

Winnett (Figure A)

1967 - Common area, grazing by cattle and sheep: May 1 - Nov. 15
1968 - Sprayed and deferred
1969 - 112 yearling cattle: Sept. 12 - Nov. 30
1970 - 70 cattle: May 20 - July 31

West Winnett (Figure A)

1971 - 1100 sheep: June 15 - July 19
1100 sheep: Sept. 15 - Oct. 31
370 cattle: May 15 - Nov. 30
1972 - 1100 sheep: June 15 - July 19
1100 sheep: Sept. 15 - Oct. 31
400 cattle: June 15 - Oct. 31
1973 - 1100 sheep: June 15 - July 19
1100 sheep: Sept. 15 - Oct. 31
320 cattle: May 21 - Oct. 31
1974 - 1100 sheep: June 15 - July 19
1100 sheep: Sept. 15 - Oct. 31
260 cattle: June 8 - June 14
400 cattle: June 15 - Oct. 27

East Winnett (Figure A)

1971 - 300 cattle: May 1 - July 10
150 cattle: Sept. 1 - Nov. 16
1972 - 350 cattle: Sept. 1 - Nov. 30
1973 - 320 cattle: May 1 - June 14
1974 - 130 cattle: Oct. 1 - Dec. 28
350 cattle: May 1 - June 30

King (Figure B)

1967 - 388 cattle: June 1 - Sept. 30
1968 - Sprayed and deferred
1969 - Cattle: Sept. 5 - Nov. 30
1970 - Cattle: May 20 - June 26
1971 - 670 cattle: June 27 - Aug. 2
1972 - 670 cattle: Aug. 16 - Sept. 22
1973 - 330 cattle: Sept. 22 - Dec. 6
1974 - Rested all year

Table B. (continued).

Sibbert spray (Figure C)

1967 - 32 cattle: June 1 - Oct. 15
1968 - Sprayed and deferred
1969 - 16 cattle: Aug. 23 - Nov. 30
1970 - 77 cattle: June 1 - Aug. 6
1971 - 77 cattle: June 1 - Aug. 25
1972 - 77 cattle: June 1 - Sept. 15
1973 - 77 cattle: June 1 - Aug. 27

Sibbert open control (Figure C)

1967 - 45 cattle: June 1 - Oct. 15
77 cattle: Oct. 16 - Oct. 31
1968 - 60 cattle: Aug. 19 - Dec. 15
1969 - 77 cattle: Aug. 7 - Nov. 6
1970 -
1971 - same as sprayed area.
1972 -
1973 -

Iverson enclosure (Figure D)

1967 - 500 sheep: Apr. 26 - May 25
150 cattle: Sept. 1 - Oct. 10
1968 - Sprayed and deferred
1969 - 125 cattle: Sept. 27 - Nov. 26
1970 - 125 cattle: Sept. 27 - Nov. 26
1971 - 100 cattle: May 20 - June 30; 170 cattle: Nov. 11 - Dec. 9
1972 - Same as 1971
1973 - 300 cattle: Oct. 21 - Nov. 20

Iverson open control (Figure D)

1967 - Cattle: May 6 - Nov. 30

Missouri Breaks (Figure E)

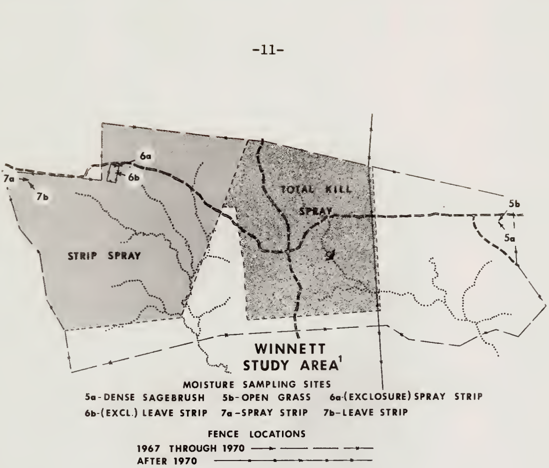
1967 - 1971 - cattle: Apr. 16 - Nov. 15
1972 - 1974 - essentially deferred

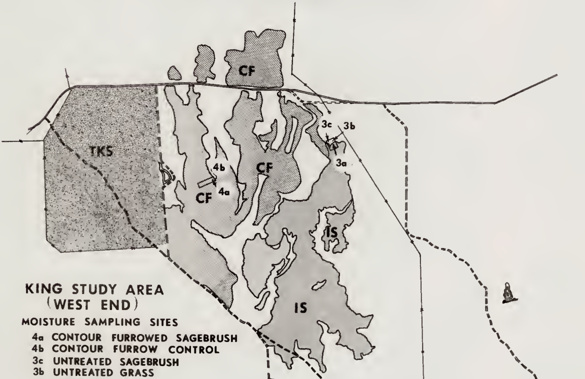
Effects of mechanical treatments were measured only on the King study area. Two hundred fifty acres were treated with a Model B contour-furrowing machine for watershed improvement. The ground was plowed to a depth of 12-14 inches; a disk following the ripper tooth opened an 8-12 inch furrow. Every 10-12 feet a kickout device left a mound (furrow-dam) in each furrow.

The procedure resulted in small catchment basins intended to prevent overland flow and promote maximum infiltration.

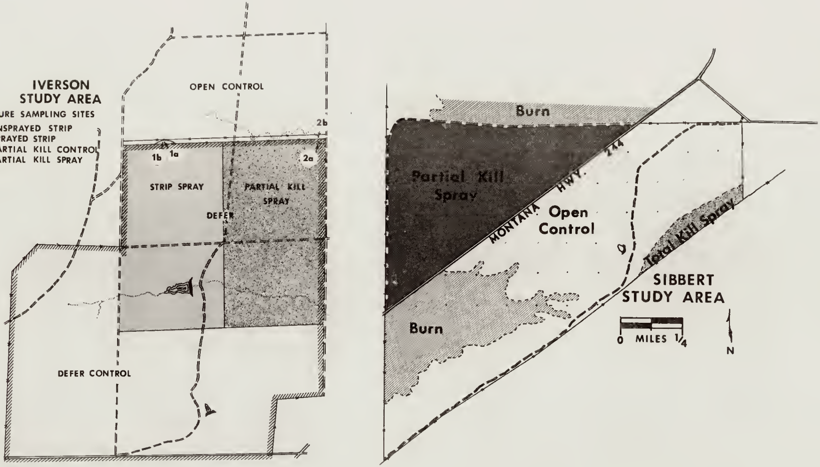
Forty-one contour-furrowed acres (north of Old Winnett Road - Figure B) were seeded at the time of treatment with a mixture of 2/3 AGSM, 1/6 STVI, and 1/6 MEOF.

Interseeding was done on 137 acres with a machine that scalped the soil surface 2-4 inches in depth and 18 inches wide at 18 inch intervals. A seed mixture comprising 2/3 AGSM and 1/3 STVI was seeded at the time of treatment.





Figures A and B. Winnett and King Treatment Areas.



Figures C and D. Iverson and Sibbert Treatment Areas. The area within the shaded boundary on the Iverson Study Area had deferred grazing treatment.

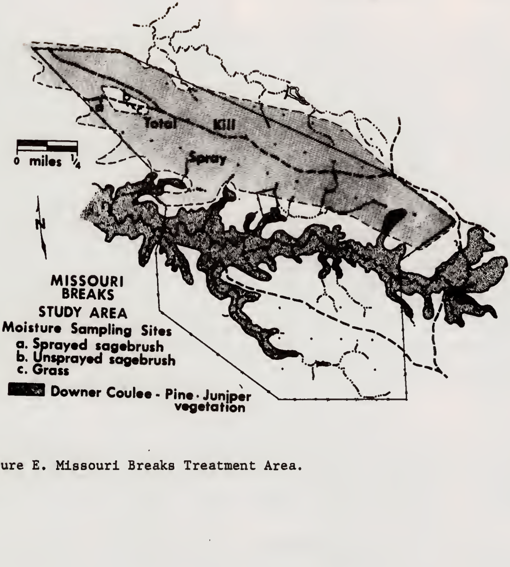


Figure E. Missouri Breaks Treatment Area.

JOB NO.: V-1.2

Job Title: Effects of Treatments on Vegetation

INTRODUCTION AND OBJECTIVES

Since 2,4-D (2,4-Dichlorophenoxyacetic acid) was recognized effective as a selective herbicide in the 1940's (Brian 1964), relatively few studies have been undertaken concerning the full gamut of ecological effects following its use on sagebrush-grasslands. The overriding objective of spray projects has been to increase the amount of grass herbage available for livestock use. Various studies have concentrated on the increase of grass production when sagebrush is treated with herbicide, but little attention has been given to the effects of such treatment on factors bearing on both game and non-game wildlife species, or of the consequences in the ecosystem as a whole.

Research in most areas shows an increase in grass productivity shortly following chemical manipulation of sagebrush rangelands (Hyder and Sneva 1956, Scheideman 1971, Hedrick, et al., 1966, Mueggler and Blaisdell 1958, Wilbert 1963, and Nichols and McMurphy 1969). However, most of these investigations were short-term and did not attempt to measure changes in total productivity of the community following treatment. Most studies indicate decreases in forb production following spraying although Wilbert (1963) could find no change. The effect of 2,4-D treatment on the forb component of a community is probably dependent on which forb species are most abundant. Hyder (1971) showed wide variability in the susceptibility of different species of forbs to 2,4-D treatment.

A long-term study by Thilenius and Brown (1974) disclosed that ten years after treatment, four sagebrush ranges in the Bighorn Mountains of Wyoming exhibited total herbage production below the pretreatment levels with similar proportions of graminoids before and after treatment. Length of postspray deferment appeared to have little effect on herbage production ten years after spraying.

Effects of mechanical treatment (contour-furrowing and interseeding) seem dependent on soil texture and type of vegetation, although results are conflicting. Houston (1971), Houston and Adams (1971) in southeastern Montana, and Branson, et al. (1962) in northeastern Montana, report fairly large increases in herbage production on fine-textured soils, whereas Branson, et al. (1966) report greater increases in herbage production on medium textured than fine-textured soils of northeastern Montana. Wight et al. (1974) show substantial production increases on sandy soils (NE Montana) following contour-furrowing and interseeding.

The objectives of this study segment were: to determine the effects of chemical and mechanical treatment of sagebrush rangeland on canopy coverage (CC), herbage production, and height of grass and forb species; to compare the effectiveness of mechanical and chemical treatments in raising herbage production; to compare the effects of herbicide and fertilizer treatments; to determine the changes in community composition following chemical and mechanical treatments; and to try and determine what soil changes may be related to changes in herbage production. For a description of the area see Jorgensen (1974).

METHODS

Measurements of vegetation changes following treatments were done with the following parameters being considered: canopy coverage, height, and dry matter production. Measurements of dry matter production were more intensive and restricted to much smaller areas than the canopy coverage and height estimations.

In the Yellow Water Triangle, permanent plots for canopy coverage and height estimations were established in 1967. Measurements were then taken at approximately the same plot locations in 1969, 1971, and 1973. In the Missouri Breaks, plots were established and measured in 1967 and 1969 (prespray) and remeasured in as close to the same location as possible in 1973 (postspray).

Table 1. Locations of canopy coverage and foliage height sample plots.

Area	Treatment[1]	Habitat (or cover) Type	No. of plots
Winnett	TK & SS	ARTR:AGDA	10
	TKS & SS	ARTR:AGSP	4
	Control	ARTR:AGDA	10
	Control	ARTR:AGSP	6
King	TKS	ARTR:AGSP	6
	TKS	ARTR:AGDA	2
	Mech.	ARTR:BOGR	11
	Mech.	ARTR:AGSP	3
	Control	ARTR:BOGR	5
	Control	ARTR:AGSP	8
	Control	ARTR:AGDA	5
Sibbert	PKS	ARTR:BOGR	9
	Control	ARTR:BOGR	9
Iverson	PKS & SS	ARTR:BOGR	6
	PKS & SS	ARTR:AGDE	3
	Control	ARTR:BOGR	10
	Control	ARTR:AGDE	4
	Control	ARTR:AGSP	5
Missouri Breaks	TKS	ARTR:AGSP	12
	Control	ARTR:AGSP	12

[1] abbreviations for treatments: TKS = total kill spray; SS = strip spray; PKS = partial kill spray; mech. = mechanical (contour-furrowed or interseeded).

Canopy coverage estimates were based on the method of Daubenmire (1959) using seven canopy coverage classes instead of six. The canopy coverage classes were:

1 - 0 to 1%
2 - 1 to 5%
3 - 5 to 25%
4 - 25 to 50%
5 - 50 to 75%
6 - 75 to 95%
7 - 95 to 100%

Heights of vegetative parts (foliage) only of plants were put into 3-inch height classes. At each plot location, estimates were made within 20 subplots situated along a 100 foot line.

In addition to the estimations of herbaceous CC and height by the above method, shrubs were measured by the line-intercept method (Canfield 1941) in 1967, 1969, and 1971 and two 50 foot lines placed at right angles to each other. In 1973, separate shrub CC's were measured according to 6-inch height classes using a 4X5 dm. plot frame as described by Pyrah (1973).

When dry matter productivity determinations were made, all parts of herbaceous plants were clipped at ground level and everything except current annual growth was discarded. Grasses were generally air-dried (except for samples collected in the life history study of AGSM-Jorgensen 1970) and forbs were oven-dried at 70° C until constant weight was reached.

In the fertilizer-spray treatment comparison study, 100-2X4.8 foot plots, separated by 2 foot wide alleys, were established on sites in the total kill spray and adjacent nonspray areas of the King study area and given complete grazing deferment. The 100 plots in each treatment were arranged in 10 blocks of 10 plots each with different applications of fertilizer randomly applied to the plots in each block using a table of random numbers. Commercial pellet fertilizers (34-0-0 nitrogen and 0-45-0 phosphorus) were weighed out and hand applied on 23 and 24, April 1969 to achieve the desired rates. Fertilization rates in lbs./A were:

Nitrogen	Phosphorus
100	100
100	50
100	0
50	100
50	50
50	0
0	100
0	50
0	0
0	0

One-half of each 9.6 foot^2 plot was clipped during the period August 11 to August 20, 1969. In July 1971 the previously clipped half of each plot, plus the other half, were clipped with the samples from each half being kept separate. Species segregated in the clipping operation were: AGSM, STCO2, AGSP, ARFR2, VIAM. All other species were lumped in miscellaneous grass and miscellaneous forb categories. *Carex eleocharis,* the only sedge of importance, was placed in the miscellaneous grass category. Because of time limitations, no attempt was made to determine ARTR production on the unsprayed site.

Samples of AGSM clipped in 1969 were analyzed for percent nitrogen (N), phosphorus (P), and potassium (K) at the Montana State University Soils Testing Laboratory to correlate uptake of nutrients with nutrient application rates.

To determine if herbicide and mechanical treatments cause increases in N, P, and K availability, samples of AGSM were clipped from different treatments on various sites on the assumption that variations in nutrient availability in the soil will be reflected by variations of nutrient content in the grass. Results of the fertilizer study showed this to be a valid assumption. Six samples were collected in each of the following areas and analyzed for percent N, P, and K at the MSU Soils Testing Laboratory: Iverson PKS, Iverson leave, Sibbert TKS, Sibbert leave, King mechanically treated, King leave, King TKS, King leave, Winnett TKS, Winnett leave. Thirty samples from each of the sprayed sagebrush, unsprayed sagebrush and open grass treatments in the Missouri Breaks were collected in August 1972 and analyzed for percent protein.

RESULTS AND DISCUSSION

Effects Of Sagebrush Spraying On Canopy Coverage

Partial kill spray on the Artemisia-Bouteloua cover type

The average amount of dead sagebrush on these areas one year after treatment was 56 percent (Table 1) with the percentage declining to 33 by 1973 compared to 12 percent on the control sites.

Canopy coverage data for bare ground, litter and herbaceous vegetation show little difference when comparing treated and control areas. Most apparent differences in CC of certain species are shown to be non-significant when tested at the 5 percent level (Table 4). A greater number of samples, with more care in relocating the samples in exactly the same spot each time, might have shown that some of these apparent differences are indeed significant.

The one statistically significant change in CC following this treatment was an increase in rhizomatous wheatgrasses (AGSM and AGDA combined). The difference became evident immediately after spraying (1969) and remained apparently undiminished through 1973. Data of Jorgensen (1970), gathered at only one site, contradict this in that they show no change in AGSM CC following spraying and a large (but untested) decrease in BOGR.

Certain complicating factors other than inadequate sampling could mask possible partial-kill spray treatment-related canopy coverage changes. These include unequal grazing pressure on the treated and control areas of the Sibbert SA (Table 2), a greater number of soil "panspots" on the Sibbert control plots as opposed to the Sibbert spray plots, possible sampling inconsistencies arising from personnel changes, and a greater number of plots in old burns on the control area.

Table 2. Mean canopy coverage on partial-kill spray and control plots[1] Artemisia-Bouteloua cover type.

	1967		1969		1971		1973	
	Prespray	Leave	Spray	Leave	Spray	Leave	Spray	Leave
Taxon								
BRGD	17	23	15	17	12	14	12	14
GRASS	46	35	49	50	57	50	50	49
FORBS	12	9	5	6	9	13	13	11
SHRUBS	12	20	12	14	11	14	14	14
SEDE	15	8	12	15	16	11	13	16
LICHENS	4	2	9	11	16	24	11	15
LITTER2	>2	1	26	13	30	25	13	10
MULCH	38	35	58	52	55	47	47	42
AGDA[2]	18	17	13	10	22	9	18	10
STCO2	2	3	6	6	8	6	6	7
BOGR	16	15	16	19	18	21	12	18
KOCR	7	4	8	6	10	7	6	5
STVI	1	2	1	<1	<1	<1	>1	<1
VIAM	6	3	<1	>1	2	3	4	3
ARFR2	>1	2	2	2	2	3	3	3
TRDU2	<1	<1	T	<1	1	<1	<1	<1
POA	3	3	2	2	5	9	>1	<1
TAOF	<1	<1	<1	<1	<1	<1	3	<1

[1] Iverson and Sibbert study areas.

[2] Includes AGSM.

Total kill spray on the Artemisia-Agropyron habitat type

Changes in canopy coverage of total grass (mainly AGSM), forbs (mainly VIAM and ARFR2), and lichens were significant on this treatment-habitat type combination.

There was no significant increase in total grass one year following treatment (Table 3), but 3 to 5 years later, total grass CC was significantly greater on the sprayed than the control sites. This change in grass CC was entirely due to changes in CC of AGSM. Treatment-related differences in CC of all other important grasses (BOGR, AGSP, STCO2, and KOCR) were insignificant. Although differences in CC of total grasses did not appear until 1971, CC of AGSM on the sprayed areas became significantly greater than on the control areas by 1969, the gap widening by 1971 and 1973.

Forb CC declined sharply immediately following spraying; a large significant difference still existed by 1973. The damage susceptibility of different species of forbs to 2,4-D varies widely. The only forb species occurring in measurable abundance in this habitat type were ARFR2 and VIAM. Both species exhibit high initial susceptibility to 2,4-D (Table 5) but the long-term effects were different. Other studies have shown that ARFR2 tops are easily killed by 2,4-D (Hyder 1971, Scheideman 1971), but that rapid basal resprouting causes quick recovery (Scheideman 1971). In the Yellow Water Triangle, spraying reduced CC of ARFR2 to levels much below those of the control areas in 1969 and 1971, but by 1973 there was no difference between sprayed and nonsprayed areas.

The effect of 2,4-D on VIAM varied considerably from that for ARFR2 because the subterranean perennating organs (rhizomes), as well as the tops of VIAM, are killed by the herbicide. Recovery of the plants in an area following herbicide treatment is only by seedling germination and establishment, and is apparently slow even where there is an abundance of vigorous seed-producing plants. Destruction of VIAM by 2,4-D was immediate (Table 3) with no apparent recovery five years later.

Selaginella densa or lichen CC's were not significantly affected by the spray treatment.

Table 3. Mean canopy coverage on total-kill spray and control plots, Artemisia-Agropyron Habitat Type (Winnett & King SA's).

	1967		1969			1971			1973		
Taxon	Spray	Leave	Spray		Leave	Spray		Leave	Spray		Leave
BRGD	15	18	13		14	13		17	12		18
GRASS	53	42	51		43	61		51	56		43
FORBS	20	15	4	*	11	6	*	16	7	*	14
SHRUBS	13	17	>1		20	<1		13	3		20
SEDE	14	17	14		16	11		19	15		19
LICHENS	8	8	8		7	11		12	15		9
LITTER2	4	11	23		19	34		25	15		12
MULCH	32	40	60		57	57		53	46		40
STCO2	6	5	6		5	2		5	5		3
AGSM[1]	18	11	13		8	28	*	12	22	*	8
BOGR	11	10	10		8	12		8	11		8
KOCR	8	5	9		8	9		8	7		6
VIAM	3	3	<1	*	2	<1	*	2	<1	*	5
ARFR2	6	5	>1	*	5	>1	*	4	3		3
TRDU2	T	T	T		<1	0		<1	<1		<1
POA	4	2	>1		<1	5		2	2		<1
TAOF	<1	<1	<1		T	T		T	<1		<1
AGSP	7	5	8		5	5		6	10		5
MEOF			T		<1						

* -Means are significantly different at $P < .05$.

[1] Includes AGDA.

Total kill spray on the Artemisia-rhizomatous Agropyron habitat type

The investigation of total kill spray effects on the Artemisia-rhizomatous Agropyron habitat type was conducted on the Winnett study area (north of highway 200) between 1967 and 1973, and on the Missouri Breaks study area (treated in 1972). The Artemisia-rhizomatous Agropyron h.t. basically differs from the Artemisia-Agropyron h.t. in that the former has little or no BOGR, STCO2 or SEDE and somewhat more AGSM, AGDA, and STVI than the latter (Jorgensen 1974).

Complications with variations in grazing pressure complicate the interpretation of data (Table 4) from the Winnett SA. Between 1967 and 1970 a fence enclosed the study area with theoretically evenly distributed grazing pressure inside. In 1970 the fence surrounding the study area was removed and replaced by one running north-south approximately through the middle (Fig. A); separating all sprayed areas to the west from untreated areas to the east. Livestock allotments have been different on either side of this fence (Table B), but the degree of grazing pressure is difficult to assess since the stock ranged over a much larger region than just the study area.

Table 4. Mean canopy coverage on total kill spray and control plots, Artemisia-Rhizomatous Agropyron habitat type (Winnett SA).

	1967		1969		1971		1973	
Taxon	Spray	Leave	Spray	Leave	Spray	Leave	Spray	Leave
BRGD	32	28	24	18	22	22	18	20
GRASS	40	40	46	32	54	48	54	38
FORBS	14	18	2 *	18	6 *	24	14	24
SHRUBS	18	24	<1 *	20	<1 *	20	2 *	22
LICHENS	<1	T	1	<1	2	2	4	3
LITTER2	4	>1	26	16	38	24	20	16
MULCH	20	24	54	55	53	52	53	46
AGDA[1]	24	26	38 *	28	42 *	32	52 *	30
KOCR	2	<1	4	2	5	3	5	4
VIAM	4	4	T	<1	<1	4	5	8
TRDU2	T	<1	T	1	0	<1	<1	1
POA (POSE)	2	<1	3	1	5	2	4	2
TAOF	T	T	T	T	T	<1	<1	<1
MEOF	0	0	T	T	0	<1	0	<1
STVI	5	8	3	3	4	3	5	3

* -Means are significantly different at $P < .05$.

[1] Includes AGSM.

Some changes took place between 1967 and later years from causes other than spray treatment. On the control plots total grass increased slightly between 1967 and 1971 and appeared to decrease slightly between 1971 and 1973. Both mulch and standing litter exhibited a response similar to that of total grass, i.e. the CC increased between 1967 and 1971 and then fell off after 1971, with no significant difference in the response between sprayed and nonsprayed plots. Because of the increases in CC of grass and litter, converse changes in bare ground occurred since 1967 on both sprayed and nonsprayed plots. Yearly increases in CC of grasses other than Agropyron (mainly KOCR and POSE) were similar on both sprayed and nonsprayed plots. An increase in lichens after 1967 apparently was independent of spray treatment. Such changes suggest that one or both of two things may have happened. One could be that the years 1967 through 1973 were more favorable climatically than immediately prior years. The other was a possible decrease in grazing pressure. In 1967 (and probably before), the entire study area was in common use by both cattle and sheep for the entire growing season (Table B). Subsequently, there was one year of deferment and a shortening of the grazing period in the other years. Intensity of use might also have decreased. Such changes would cause increases in canopy coverage of some species regardless of spray treatment.

The dominant grasses, AGSM and AGDA, exhibited little canopy coverage change between 1967 and 1973 on the untreated area but nearly doubled on the sprayed area (Table 4). This relative increase in CC of rhizomatous wheatgrasses on sprayed plots is responsible for the relative increase in CC of total grasses on sprayed plots between years.

Forb CC on the untreated plots remained relatively unchanged between 1967 and 1973 but decreased sharply on the spray plots immediately after treatment. Between 1969 and 1973, forb CC on spray plots increased steadily to about 60 percent of that on the unsprayed plots. Although VIAM is the most abundant single forb species in this habitat type, most of the CC of forbs is contributed by a large number of forb species, many of which are less susceptible to 2,4-D damage than VIAM. Individually, these forb species are relatively inconsequential; CC data are inadequate to show treatment-related differences.

The reaction of VIAM to herbicides in this habitat type was different than in the Artemisia-Agropyron h.t. Following the expected reduction of CC to almost zero immediately after treatment, CC began to increase sharply, until by 1973 it was over half that of the CC on the unsprayed area. On the unsprayed area the CC of VIAM also showed a drastic decline in 1969 (almost as great as that of the spray area) followed by an increase to greater than 1967 levels. With present knowledge, this response is difficult to explain.

Although the data appear to show that STVI has increased on the spray areas relative to the unsprayed areas, the difference was not significant ($P < .05$) in any year.

Changes of CC of TRDU2, TAOF, and MEOF relative to both treatment and time were inconsistent. An extremely large number of samples would be needed to show any spray treatment-caused changes possibly occurring in these species.

Data from sample plots in the Missouri Breaks study area were gathered twice; once before spraying and once after spraying. No information on year to year changes after treatment is available. Because the entire area was essentially deferred for the duration of the postspray study period (Table B), it is assumed that the causes of significant difference between sites result solely from the presence or absence of spray treatment.

The amount of bare ground before treatment in the Missouri Breaks was higher on the control than the prespray plots, but in 1973, one year after treatment, the situation had reversed (Table 5). Spray treatment works in two opposing ways to affect the amount of bare ground; reduction of forb and shrub canopy coverage and increasing of grass and litter canopy coverage. In this case, the total decrease in shrub and forb canopy coverage due to spray treatment was sufficient to produce a relative increase in bare ground in spite of the large increase in total grass canopy coverage.

One of the most spectacular effects of the spray treatment was the large relative reduction of yellow sweetclover (MEOF) CC. Canopy coverage of sweetclover on the treated plots in 1973 was about the same as before spraying but on the untreated plots the 1973 canopy coverage was more than four times the 1969 CC and almost ten times greater than the same-year CC on the sprayed plots. However, in 1974 the situation was reversed; a large sweetclover "bloom" occurred on the sprayed but not on the unsprayed plots. Since sweetclover "blooms" appear to occur in alternate years, it is possible that from now on "blooms" may alternate between the sprayed and unsprayed areas.

Table 5. Mean canopy coverage on total kill spray and control plots in the Artemisia-Rhizomatous Agropyron habitat type (Missouri Breaks SA).

	1969 (prespray)[1]			1973 (postspray)[1]			1974[2]		
Taxon	Prespray		Control	Spray		Control	Spray		Control
BRGD	20	*	24	21	*	19	9	*	26
GRASS	43		48	53	*	45	61	*	30
FORBS	18		18	8	*	34	<1	*	2
SHRUBS	18	*	11	2	*	13	0	*	17
LICHENS	<1		6	>1		7	0	*	0
LITTER2	12		10	19		14	54	*	22
MULCH	52	*	47	56		58	59	*	41
AGSM	31		31	39	*	30	57	*	29
AGSP	4		6	3		2	0		0
KOCR	<1		4	2		5	0		0
POA	4		3	3		2	>1		0
STVI	3		2	5		2	0		0
VIAM	4		3	<1	*	2	0		.07
MEOF	1		6	3	*	28	0		0
TRDU2	2		<1	0		T	0		0
TAOF	T		0	0		0	0		0
SPCO							.15		.17

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* -Means are significantly different at P .05.

[1] Plots located over the entire study area.

[2] 40 randomly distributed plots per treatment located only in the vicinity of the soil moisture blocks.

Forbs other than sweetclover apparently decreased between 1969 and 1973 on both treated and untreated plots. Data for TRDU2 and TAOF are insufficient for conclusions concerning the effect of the spray treatment. Vicia was sharply reduced following spraying; a reaction similar to that noted on the TKS sites of the Winnett and King SA's.

Of the grasses, the only species significantly affected by the spray treatment was AGSM. In any habitat type containing both ARTR and AGSM, one could safely say that herbicide treatment of sagebrush will increase CC of AGSM, but the effects on other grass species are less predictable.

In 1974, following two years without grazing after spraying, CC differences were much more evident than in 1973. An intensive comparison of CC's between sprayed and unsprayed parts of one ARTR-AGSM stand (1974 of Table 5) illustrates these differences, although such data should not be extrapolated for the study area as a whole.

Although the CC of VIAM appears less on the sprayed than the control site, the occurrence of this species was so scattered in this particular area that the difference was not statistically significant. Canopy coverage of SPCO was apparently unaffected, suggesting a resistance to 2,4-D damage.

Effects of Sagebrush Spraying on Plant Height

Plant height (height of vegetative parts only, was estimated in this study), in addition to being a measure of importance as cover for wildlife, is often an indicator of the degree of vigor of individual plants.

Significant differences (5%) in foliage height between sprayed and unsprayed sites occurred only for AGSM and STCO2. Slight, but not significant at 5 percent, differences were noted for STVI, VIAM, and KOCR. All differences were greatest in 1969, one year after treatment, and declined thereafter (Table 6).

The effects of spray treatment on the factor or factors causing the small and transient changes in plant height are short-lived. Increases in available N (presumably released from killed vegetation) following spraying could be responsible for greater individual plant size.

Effects of Mechanical Treatments on CC and Height

Mechanical treatments (results from both contour-furrowing and interseeding are combined) significantly affected the canopy coverage of some components of the ecosystem.

Table 6. Mean foliage heights (cm.) on spray and control plots, all areas, all spray treatments.

Area-Species	1967		1969		1971		1973	
	Spray	Leave	Spray	Leave	Spray	Leave	Spray	Leave
Partial-Kill								
AGSM	16	16	15 *	12	16 *	13	18	16
STVI	12	13	13	12	19	12	20	18
STCO2	9	10	8	6	11	9	10	8
KOCR	6	5	5	4	7	6	5	5
VIAM	10	10	9	7	7	7	10	7
ARFR2	8	8	4	4	7	6	4	4
BOGR	4	4	4	4	4	4	4	4
Total-Kill Spray-Artemisia: Agrop. h.t.								
AGSM	ID[1]		16 *	13	ID		21	19
STCO	ID		10 *	8	ID		11	10
ARFR2	ID		4	4	ID		5	4
AGSP	ID		17	18	ID		23	23
VIAM	ID		7	7	ID		8	9
KOCR	ID		6	5	ID		5	5
BOGR	ID		4	4	ID		4	4
TKS-ARTR: Rhiz-Agrop. h.t. - Winnett SA								
AGSM	18	18	20 *	17	19	17	21	21
STVI	20	19	19	18	22	21	24	24
KOCR	7	8	8	7	10	6	5	8
VIAM	12	12	5	8	8	7	9	9
Missouri Breaks SA								
AGSM			24	22			23 *	18
STVI			24	21			22	22
KOCR			10	8			9	8
VIAM			18	16			10	9

* -Means are significantly different at P < .05.

[1] Insufficient data.

A large and significant decrease in CC of total grass resulted from the treatments. Such a traumatic form of treatment probably would adversely affect many plants of the community. About 3½ years after treatment (1971) the difference in grass CC was gone, and by 1973, grass CC appeared to be higher (but not significantly at 5%) on the treated plots than on the untreated ones (Table 7).

Table 7. Canopy coverage on mechanically-treated and control plots, King SA, 1967-1973.

	1967		1969			1971			1973		
Taxon	Mech.	Contr.	Mech.		Contr.	Mech.		Contr.	Mech.		Contr.
BRGD	14	13	44	*[1]	7	24	*	16	22	*	12
GRASS	49	43	30	*	45	50		49	45		41
FORBS	14	14	10		9	17		12	12		9
SHRUBS	13	16	15		19	14		15	18		18
SEDE	24	21	4	*	29	4	*	27	4	*	30
LICHENS	5	5	1	*	9	3	*	15	4	*	14
LITTER2	5	8	16		20	28		25	7		6
MULCH	24	33	40	*	62	50		49	32		32
AGSM	15	14	14	*	6	26	*	8	22	*	10
STCO2	4	4	4	**	8	4	**[2]	9	4		4
BOGR	24	14	4		10	7	**	14	5		8
KOCR	4	4	4		7	4		9	3		7
VIAM	3	3	2		2	2		2	4		3
ARFR2	4	6	4		4	6		5	3		2
TRDU2	T	T	<1		<1	T		T	<1		<1
POA	2	2	1		1	3		3			
AGSP	4	4	2		4	2		7	2		5
STVI	1	2	2		T	1	*	T	2	**	T
TAOF	<1	<1	<1		<1	<1		<1	<1		<1

[1] *Means are significantly different at P <.05.

[2] **Means are significantly different at P <.005.

The effects of such treatment on grass varies with species (Table 7). Canopy coverage of BOGR and STCO were both significantly reduced by the treatment, whereas CC's of AGSM and STVI were significantly increased. Changes in CC of AGSP and KOCR were slight and not significant (however, changes in dry matter production of these two species is a totally different story as discussed later).

Foliage heights (Table 8) of AGSM, STCO, and KOCR were significantly increased for at least 2 years following treatment. A significant difference in AGSM and STCO heights was still evident in 1971 but not for KOCR. Data were not sufficient to show if changes occurred in AGSP and STVI foliage heights.

Heights and CC of VIAM and ARFR2 were not significantly affected by treatment.

Table 8. Foliage heights (cm.) of vegetation on mechanically treated and control plots, King SA, 1967-1973.

	1967		1969		1971		1973	
Taxon	Mech.	Contr.	Mech.	Contr.	Mech.	Contr.	Mech.	Contr.
AGSM	16	18	19 **[1]	13	19 **	15	21	18
STCO2	8	9	12 **	7	13 *[2]	10	12	10
BOGR	3	3	3	3	3	3	3	3
KOCR	5	5	8 **	5	9	8	6	5
VIAM	10	11	10	8	10	8	12	8
ARFR2	10	13	5	4	6	5	5	4
POA	5	6	5	4	6	5	5	4
AGSP	18	22	20	18	22	20	26	23
STVI	20	ID[3]	16	16	19	ID	23	ID

[1] ** Means are significantly different at $P < .005$.
[2] * Means are significantly different at $P < .05$.
[3] ID Insufficient data.

Effects of Treatments on Dry Matter Production.

Various areas were sampled (often in connection with other studies) to determine changes in dry matter productivity (yield) following treatments.

The fertilizer study conducted between 1969 and 1971 on the King SA provided data comparing effects of TKS with nonspray plots under a complete lack of grazing. Results of this study are more completely discussed later, but the differences in yield between sprayed and non-sprayed plots are discussed here (Fig. 1).

In 1974, nine-hundred randomly distributed 2X5 dm. plots were clipped, 300 in each of three treatments: total kill spray, contour-furrowed, and control. The sites were virtually identical in all respects except for type of treatment and possibly grazing pressure.

Total kill spray produced a large, significant increase in yield of AGSM and STCO2, evident from one year after spraying until 1974, six years after spraying (Fig. 1 and 2). Although it may appear that the treatment-related difference in yield of these grasses diminished between 1969 and 1974, this is not a safe conclusion due to the different nature of the clipping experiment in 1969-71 and the experiment in 1974. The latter experiment consisted of a much greater number of samples collected over a larger area. The other major grass species sampled in 1974, KOCR, did not produce significantly more forage on the sprayed area compared to the control area.

The most dramatic productivity change between years was the increase in yield of AGSP between 1969 and 1971 on both sprayed and control plots (Fig. 1). This very large increase (about 440% on both treatments) was

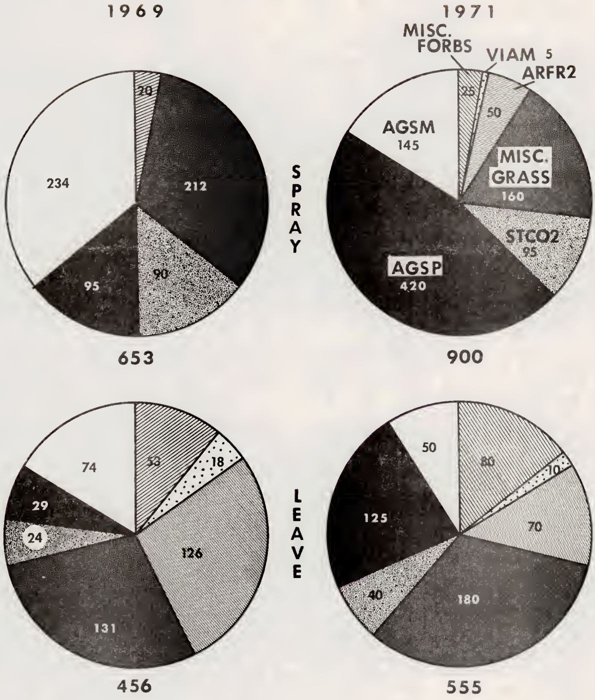


Figure 1. Mean dry matter production on sprayed and unsprayed fertilizer plots - comparison between 1969 and 1971, lb/A, King study area.

most likely due to the complete removal of the plots from grazing pressure following the construction of livestock-excluding fences in early 1969. Changes in yield of AGSM and STCO2 between years were nonexistent or small compared to AGSP.

Yield of certain forbs was severely reduced by spray treatment as expected. Dry matter production of ARFR2 and VIAM in 1969 was unmeasurable on sprayed plots (Fig. 1). By 1971, yield of ARFR2 on sprayed plots was more than two-thirds that of control plots and yield of VIAM on sprayed plots was half that of control plots. Data of 1974 (Fig. 2) show that yield of ARFR2 on sprayed plots was more than 3.6 times greater than on controls. However VIAM yield on sprayed plots was only about one-eighth that on controls. This suggests that the resprouting ability of ARFR2 enables it to quickly recover following herbicide treatment and to make use of the presumed "green-manuring" effect and reduction in competition to attain a degree of dominance not possessed before spraying.

VIAM plants, completely killed by 2,4-D, must become reestablished by seed; a very slow process in view of the removal of the immediate seed source and low dispersal capability of the seeds. After 6 years, TAOF yield was the same on both sprayed and control plots (Fig. 2). Because the fruits of TAOF are wind-disseminated this species can rapidly reinvade areas of prior removal.

Figure 7 illustrates that the percent of total dry matter production contributed by grasses decreased slightly between 1969 and 1971 on the sprayed plots, but increased on the unsprayed plots. This is discussed in more detail on P.47.

Other dry matter production data, concerned mainly with AGSM, were gathered in connection with the soil moisture study and by Jorgensen (1970). These data all show increases in AGSM yield following 2,4-D treatment compared to nonsprayed areas (Fig. 3 and 4).

The AGSM yield increases were all due to a greater number of grass stems per unit area rather than larger individual stems (Jorgensen 1970:40).

Contour-furrowing (dry matter production on the interseeded area was not measured) resulted in greater yield of some, but not all, grasses (1974) when compared to no treatment (Fig. 2). *A. spicatum* showed the greatest difference, with almost 3.5 times as much yield on the contour-furrowed sites than the adjacent controls. Yield of AGSM on treated sites was about twice that of controls. Houston and Adams (1971), working on clayey range sites in southeastern Montana, noted increases of 650 percent in AGSM production one year after interseeding and 300 percent three years after interseeding. This agrees with our results showing a difference in AGSM production of 218 percent six years after treatment (Fig. 2). Wight and Siddoway (1972) also noted increases in AGSM (and AGDA) yield on CF sites of eastern Montana.

The large decrease (1974) in yield of KOCR following contour-furrowing (not apparent from CC or height estimates) is difficult to explain.

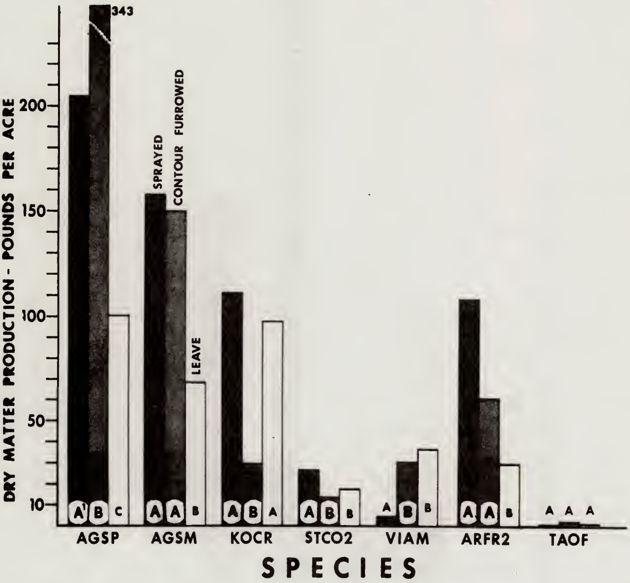


Figure 2 . Mean dry matter production of selected herbaceous species on sprayed, contour-furrowed, and control sites, lb/A, King study area, 1974.

[1] Different letters indicate significant differences at $P < .05$.

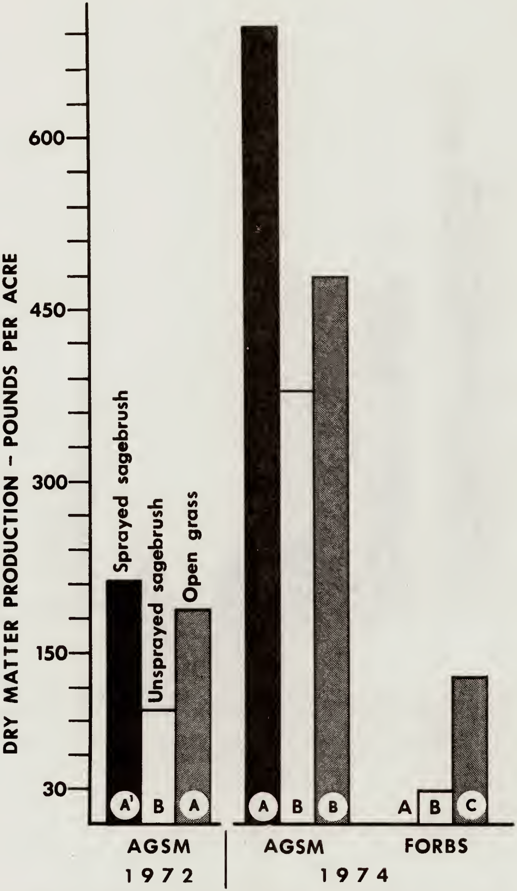


Figure 3 . Mean dry matter production on sprayed and control sites, lb/A, Missouri Breaks study area, 1972,1974. [1]Different letters indicate significant differences.

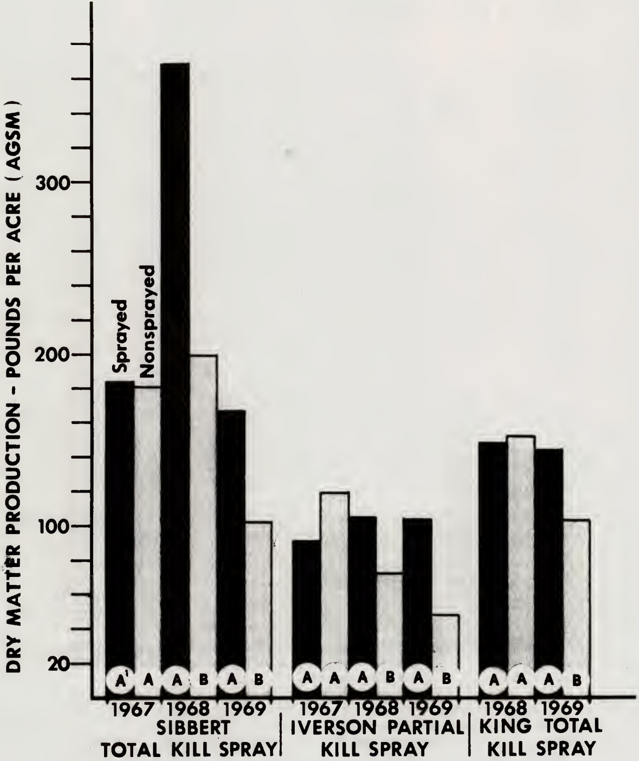


Figure 4 . Mean dry matter production of AGSM on spray and control plots of the Sibbert, Iverson, and King study areas, lb/A, 1967 through 1969.

[1] Different letters indicate significant differences at $P < .05$.

Apparently, plants of this species are very severely disturbed by treatments that disrupt the soil and do not reestablish in formerly occupied areas for extended periods.

Production of STCO2 was not significantly affected by contour-furrowing, at least not six years after treatment.

Houston and Adams (1971) report that BOGR production, on mechanically-treated sites similar to ours, was 70 percent less than on control sites three years after treatment. Presumably, production of BOGR would have been shown to be less on our contour-furrowed plots than the controls in 1974 had it been measured. Canopy coverage data (Table 8) from 1973 do not indicate a significant difference in BOGR between mechanically-treated and control plots, but as in the case of KOCR, CC estimations are not necessarily good indicators of dry matter production. In 1969, 1½ years after furrowing, CC of BOGR was much less on the mechanically treated than the control plots, with the difference rapidly becoming smaller in later years.

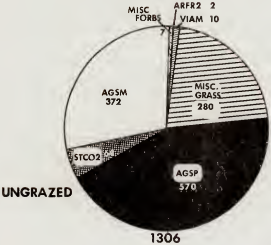
Effects of contour-furrowing on VIAM, ARFR2, and TAOF, supplying probably at least 90 percent of the total forb biomass, varied with the species. After 6 years there was no difference in dry matter production of VIAM and TAOF between treated and control plots. Yield of ARFR2 on treated sites was about double that of the controls. Wight and Siddoway (1972) report that contour-furrowing on panspot range sites in eastern Montana resulted in reduced yields of SEDE and OPPO.

The preceding discussion presumes that all factors except type of treatment were held constant while investigating the effects of contour-furrowing on dry matter production. However, there is a good possibility that grazing pressure was not a constant factor as desired. Although data are lacking to substantiate this, general observations indicate that livestock use of the treated areas was less than the adjacent untreated areas, probably because of the difficulty of walking on the furrowed ground tended to discourage use by cattle. All of the dry matter production differences, except KOCR, between contour-furrowed and control areas as discussed above, could be at least partially explained by differences in grazing pressure.

A clipping study done in 1972 in the same areas as above, showed the effects of grazing on certain species (Fig. 5). *A. smithii*, and AGSP, increased on the protected plots (since early summer 1969) relative to heavily grazed plots a few feet away. Production of STCO2 did not change. Production of miscellaneous grasses (mostly KOCR and BOGR) decreased on protected plots. No difference was evident for VIAM, but production of ARFR2 was higher on the grazed plots than the protected ones, indicating the effects of release of these species from grazing pressure are very similar to the effects of contour-furrowing.

Effects of Treatments on Water Content (succulence) of Forbs

In connection with the 1974 study of effects of herbicide and mechanical treatments on dry matter yield of grasses and forbs, water content



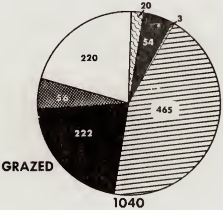


Figure 5. Dry matter production of herbaceous vegetation on grazed and ungrazed plots, lb/A, King study area, 1972.

of three forbs was determined. This is expressed as percent water on a dry matter basis as with soils, so that percentages may be, and usually are, over 100.

For TAOF, no significant differences in percent water were noted between treatments (Fig. 6).

Both ARFR2 and VIAM had significantly higher moisture percentages on the control sites than on either the sprayed or contour-furrowed sites. There was no difference between the spray or contour-furrow treatments.

Since these plants are considered homeohydric (maintaining essentially constant cellular moisture levels in the face of varying soil moisture and air humidity) (Walter 1973), some treatment-related change in the soil, other than soil moisture, apparently is affecting the physiology of certain plants such that they tend to hold more water than normal in relation to other materials. The causative nature of the relationship between treatments and turgidity of plant cells is unknown.

Comparisons of Fertilizer and Spray Treatments

For a review of fertilizer studies on Great Plains rangelands up to 1961 see Smoliak (1965).

Since 1961, various fertilization studies have been conducted, many with different objectives. Reed and Dwyer (1971) found the efficiency of water use (units of dry matter produced per unit of water used) of BOGR increased following application of nitrogen (N). Power (1967) concluded that N, added to the soil in excess of the immobilizing capacity of the ecosystem, would remain in an available form in the soil for many years until used by vegetation. Application of 30 lbs. nitrogen per acre (N/A) (Lorenz and Rogler 1967) on mixed prairie rangeland of North Dakota increased total root weight, but 90 lb. N/A applications were necessary to increase top weights. Little work has been done concerning changes in species composition following fertilization. Goetz (1969), in southwestern North Dakota, found total basal cover was reduced following application of N due to a replacement of BOGR by AGSM, ARFR2, and ARLU. Smoliak (1965) determined that applications of manure and straw-plus-fertilizer caused a decrease in BOGR and SEDE basal area, and increase in AGSM. Bouteloua was found to accumulate less N than AGSM or STCO2 (Houston, et al. 1973).

In only one study was a comparison made between the effects of 2,4-D treatment, N-fertilization, and 2,4-D treatment plus fertilization (Nichols and McMurphy 1969). Their results, gathered over a period of three years, seemed somewhat inconsistent and difficult to interpret. Grass production on sprayed, non-fertilized plots was higher than that of unsprayed plots in some, but not all years. Fertilizer rates of 120 lb. N/A produced significant increases of grass production over 0 lb. of N/A in only two out of three years. The herbicide plus 120 lb. N/A

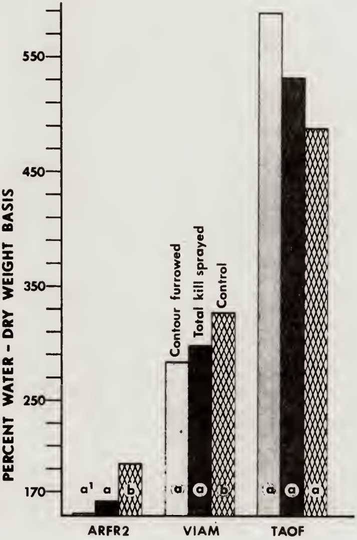


Figure 6 . Mean percent water (succulence) of selected forbs on sprayed, contour-furrowed, and control sites, King study area, 1974.

[1] Different letters indicate significant differences.

treatment resulted in higher production than the 120 lb. N/A treatment alone in all years although the differences were not always significant.

In contrast to most other studies on rangeland fertilization, ours shows that although significant differences between fertilized and unfertilized plots existed the first year, two and a half years after treatment the differences were gone (Tables 9, 10, 11). None of the other studies were done in habitat types containing AGSP and ARTR as dominant species. It is possible that the application rates of N necessary to give results lasting 2 years or longer are larger for the Artemisia-Agropyron habitat type than for mixed-prairie habitat types where most other studies were conducted.

Total production data (except sagebrush) in 1969 (Table 9) show that responses from fertilization alone (unsprayed) were segregated into two distinct groups. One group, containing all those plots five no N (but with varying amounts of P, averaged 441 lbs/A of production compared to 983 lbs/A for the other group containing plots fiven either 50 or 100 lbs. N/A. No difference in production could be seen between 50 and 100 lbs. N/A on the unsprayed site.

On the sprayed site there were three distinct groups of responses. These groups were correlated with 0, 50, and 100 lb./A application rates of N. The average of 665 lbs./A production on the 0 lb. N/A sprayed plots was significantly greater than production on similar plots on the unsprayed site. Fifty lbs. N/A on sprayed plots resulted in production figures very similar to 100 lbs. N/A on the unsprayed site, whereas 100 lbs. N/A on the sprayed site resulted in much higher production compared to plots given 100 lbs. N/A on the unsprayed site (Fig. 7). Different application rates of P were totally unrelated to yield responses on both sprayed and unsprayed sites (Tables 9, 10 and 11).

On the sprayed site, almost all of the production response to different N application rates was attributed to grass; a consequence of the almost total obliteration of forbs by the spray treatment. On the unsprayed site, grasses and forbs reacted about equally to the fertilizer applications (Fig. 7).

The differences in response to fertilizer applications on the sprayed and unsprayed sites could have three explanations. One of these is the possibility that sagebrush, not sampled and therefore the production of which does not appear with the total production figures, absorbed much of the applied N, reducing the amount that could be absorbed by grasses and forbs in turn affecting their dry matter production. Another explanation could be that since forbs were not killed on the unsprayed site, they would have absorbed a greater proportion of the added N on that site than the other. If the degree of response of forbs to N applications is less than that of grasses, the effects of differential applications of N on total production would be less. The third possible explanation concerns the release of available N in the soil following death of sagebrush plants.

Table 9. Mean total herbaceous dry matter production following fertilizer and spray treatments, lb./A.

	Fertilizer Application Rate[1]								
	10:10	10:5	10:0	5:10	5:5	5:0	0:10	0:5	0:0
1969									
Spray	154a[4]	1452a	1463a	1225b	1159b	1158b	624c	729c	653c
Leave	1089a	949a	1051a	905a	864a	1038a	411b	440b	456b
1971									
A[2]									
Spray	896	793	901	765	813	953	825	834	747
Leave	441	380	386	406	437	470	316	405	442
B[3]									
Spray	696	772	742	820	791	803	844	940	734
Leave	441	374	367	405	437	468	314	332	442

[1] Application rates for N and P in lbs. per acre divided by ten. Example: 10:10 = 100 lbs./A of N and 100 lbs./A of P.

[2] A- plots previously clipped in 1969.

[3] B- plots not previously clipped in 1969.

[4] Means in the same row followed by the same letter are not significantly different at $P < .05$).

This N would be added to any which might be present as a result of fertilization. The 1969 production responses from 50 and 100 lb. N/A application rates are similar on the unsprayed site, but are different from each other on the sprayed site, suggesting that some N level considerably in excess of 100 lb./A, such as might result from increased available N from killed sagebrush and forbs in addition to that which was applied, was necessary to produce a yield response above that resulting from application of 50 lb. N/A. If this explanation were accepted, the fact that the 50 lbs. N/A response on the sprayed site is very similar to the 100 lbs. N/A response on the unsprayed site would suggest that the total kill of sagebrush caused a release of N into the soil equivalent to about 50 lbs. N/A. This line of reasoning of course does not take into consideration the preceding two alternative explanations for spray-nonspray differences in response. Additional work, discussed later, was done to determine whether or not spraying actually results in a significant increase of available N in the soil.

Individual species response to different rates of N application varied between the sprayed and nonsprayed sites.

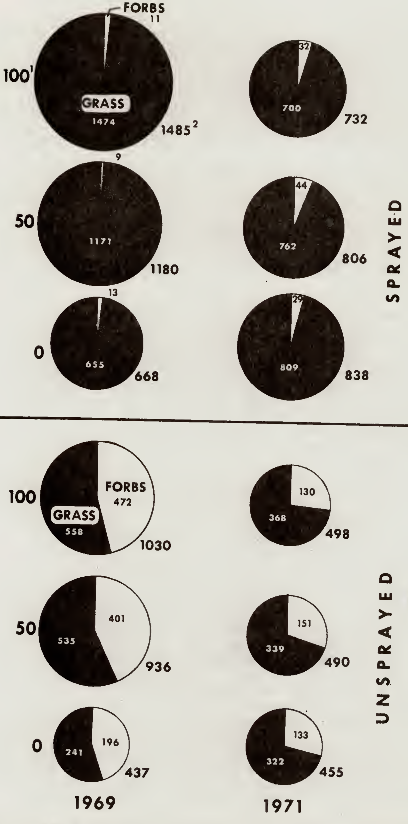


Figure 7. Mean dry matter production of grass and forbs on sprayed and unsprayed fertilizer plots, lb/A, King SA, 1969,71. ¹lb/A N-application rate. ²lb/A dry matter production.

Table 10. Mean dry matter production of grasses following fertilizer and spray treatments, lb./A.

	Fertilizer Application Rate[1]								
	10:10	10:5	10:0	5:10	5:5	5:0	0:10	0:5	0:0
AGSM									
1969									
Spray	655	579	486	448	363	488	232	315	234
Leave	151	188	173	116	129	127	63	90	74
1971									
A[2]									
Spray	198	164	171	100	145	247	181	203	160
Leave	36	68	71	25	27	47	27	35	40
B[3]									
Spray	136	120	150	146	101	212	111	125	104
Leave	35	48	48	30	21	46	65	28	29
AGSP									
1969									
Spray	293	288	230	152	164	262	105	119	95
Leave	47	33	13	32	16	27	11	12	29
1971									
A									
Spray	528	422	393	404	395	533	388	342	261
Leave	111	72	76	81	81	77	40	75	92
B									
Spray	396	417	344	379	451	358	383	478	371
Leave	116	130	121	125	94	76	93	133	43
STCO2									
1969									
Spray	123	199	231	203	149	85	48	80	90
Leave	34	28	31	34	58	37	21	14	24
1971									
A									
Spray	47	78	106	92	77	49	48	87	92
Leave	24	19	18	30	33	29	27	12	25
B									
Spray	48	77	94	81	63	87	73	76	80
Leave	19	19	10	27	21	10	36	11	29
MISC. GRASSES									
1969									
Spray	460	380	500	411	475	311	227	209	212
Leave	354	262	358	337	334	358	124	128	131
1971									
A									
Spray	114	125	207	158	192	109	197	191	208
Leave	203	142	175	203	207	248	170	172	187
B									
Spray	95	121	105	133	147	127	248	225	155
Leave	216	159	186	207	180	179	160	172	168

Table 10 (continued).

	Fertilizer Application Rate[1]								
	10:10	10:5	10:0	5:10	5:5	5:0	0:10	0:5	0:0
TOTAL GRASSES									
1969									
Spray	1531a[4]	1446a	1447a	1241a	1151b	1151b	612c	723c	633c
Leave	586a	511a	575a	519a	537a	549a	218b	244b	259b
1971									
A									
Spray	886	788	877	754	810	918	815	823	722
Leave	374	301	339	338	349	399	264	314	344
B									
Spray	687	736	692	739	762	784	814	905	709
Leave	385	355	363	389	315	311	354	344	268

---

[1] Application rates for N & P in lbs. per acre divided by ten.

[2] A - plots previously clipped in 1969.

[3] B - plots not previously clipped in 1969.

[4] Means in the same row followed by the same letter are not significantly different at $P < .05$.

The only two segregated species exhibiting responses correlated to N application rates on the non-sprayed site in 1969 were AGSM and ARFR2. *Agropyron smithii* production response was extremely well correlated with all three rates of fertilizer application (0 lbs. N/A considered as a rate) (Table 10, Fig. 8). *Artemisia frigida* showed no difference in response between the 100 and 50 lbs. N/A rates, but produced significantly less dry matter where no N was added (Table 11, Fig. 8). One or more species in the miscellaneous grass category (comprising POSE, POCA, STVI, KOCR, BOGR, CAMO, and CAEL3) reacted the same as ARFR2 (Table 10, Fig. 8).

On the sprayed site, AGSM showed a different response to each of the three rates of N application. Responses of STCO2 and AGSP were different depending on whether N was added or not but there was no difference in response of these two species between the 50 and 100 lbs N/A application rates (Fig. 8). Miscellaneous grasses exhibited a similar response to those of STCO2 and AGSP.

Because of the difference in grass species response to various N application rates on the sprayed and nonsprayed sites, the response of total grass production also varied between the two sites.

In 1971, no correlation between rates of N application and dry matter production of any species could be found (Fig. 8). The year 1971 was very dry during the critical periods of the growing season (Fig. 9)

Table 11. Mean dry matter production of forbs following fertilizer and spray treatments,[1] lb./A.

	Fertilization Rate[1]								
	10:10	10:5	10:0	5:10	5:5	5:0	0:10	0:5	0:0
ARFR2									
1969									
Spray	Trace	T	T	T	T	T	T	T	T
Leave	406a[4]	275a	385a	287a	181b	311a	111c	110c	126c
1971									
A[2]									
Spray	.8	4.2	6.2	8.2	2.8	26	5.8	8.8	21
Leave	23	12	14	22	21	19	18	43	32
B[3]									
Spray	9	33	50	21	21	15	23	29	19
Leave	54	62	55	55	42	55	105	62	77
VIAM									
1969									
Spray	T	T	T	T	T	T	T	T	T
Leave	11a	10a	5a	7a	8a	7a	16a	8a	18a
1971									
A									
Spray	.02	.02	.4	0	.2	.2	1.6	1.6	.4
Leave	11	7	2	1.4	3.6	5.4	4.2	8.6	4
B									
Spray	0	.2	0	.6	.4	.8	0	.4	2.8
Leave	6.6	8.2	.8	2	5.2	3.2	2.4	6.6	5.8
MISC. FORBS									
1969									
Spray	11a	6a	16a	11a	8a	7a	12a	6a	20a
Leave	86a	153a	86a	92a	138a	171a	66a	78a	53a
1971									
A									
Spray	2.2	.04	17	2.6	.04	8.2	2.4	.6	22
Leave	32	60	30	44	64	44	30	39	62
B									
Spray	.02	3.2	.2	60	7.4	3.4	5.8	6.4	3.6
Leave	19	41	144	112	98	82	70	52	21
TOTAL									
1969									
Spray	11a	6a	16a	11a	8a	7a	12a	6a	20a
Leave	503a	438a	476a	386a	327a	489a	193b	196b	197b
1971									
A									
Spray	3	4.4	24	11	3.4	35	10	11	25
Leave	66	79	46	67	88	71	52	91	99
B									
Spray	9	36	51	82	29	19	28	36	25
Leave	79	112	72	169	145	140	177	120	67

---

[1] Application rates for N & P in lbs. per acre divided by ten.

[2] A-plots previously clipped in 1969. [3]/plots not previously clipped in 1969.

[4] Means in the same row followed by the same letter are not significantly different at $P < .05$.

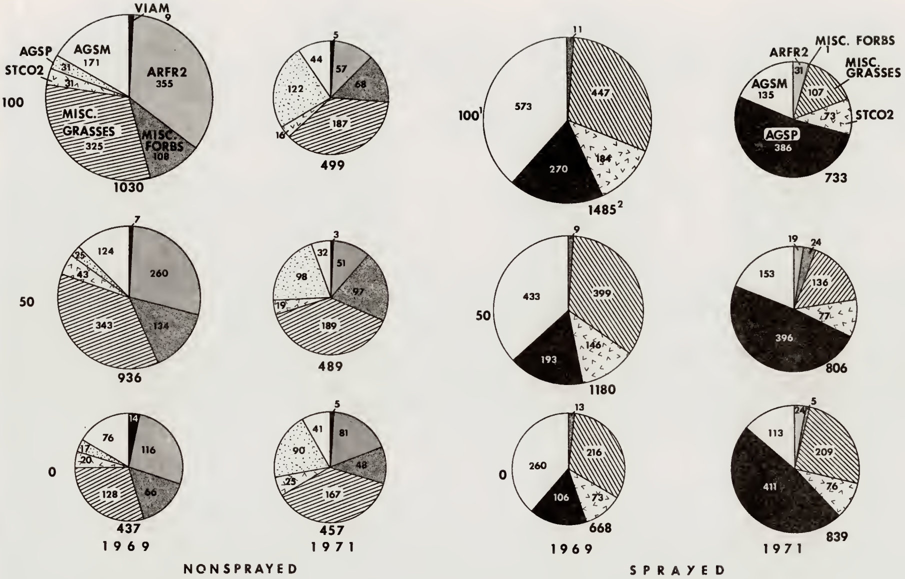


Figure 8. Mean dry matter production of herbaceous species on sprayed and control plots following application of nitrogen at different rates, lb/A, King study area, 1969 and 1971. [1]Application rate of nitrogen, lb/A. [2]Dry matter production, lb/A.

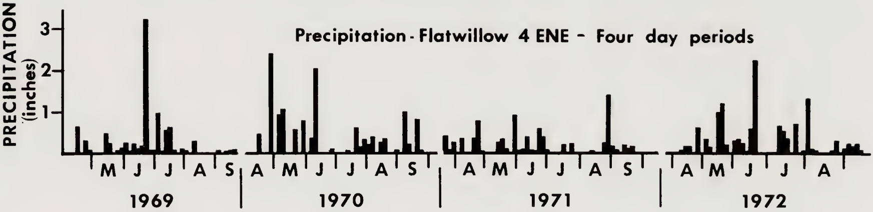


Figure 9. Precipitation at Flatwillow 4ENE, Montana, 1969-1972.

and moisture rather than nutrient status of the soil may have been the prime limiting factor on productivity. If this was the case, measurements taken in subsequent wetter years may have again shown significant differences in production correlated to the different N application rates. However, these measurements were not taken, with the data we have it cannot be concluded that the effects of fertilization persist more than one year after application.

Differences in productivity between sprayed and nonsprayed plots were still very evident in 1971 (Fig. 1). Total production on sprayed plots was about 1.6 times that of the unsprayed plots, although it must be remembered that production of sagebrush was left out of these figures. Had yield of sagebrush been measured, the difference between sprayed and unsprayed plots probably would have been very small.

Differences in 1971 production between plots that had been previously clipped in 1969 and those that hadn't were sometimes significant (Table 12).

Table 12. Mean 1971 dry matter production, previously clipped and unclipped plots, lb./A air dry.

	Sprayed			Unsprayed		
	Clipped		Unclipped	Clipped		Unclipped
AGSM						
100[1]	178	*	135	58		43
50	164		153	33		33
0	181	*	113	34		41
AGSP						
100	448		385	86	*	122
50	444		396	80	*	98
0	330		411	69		90
STCO2						
100	77		73	20		16
50	73		77	31		19
0	76		76	21		25
MISC. GRASS						
100	149		107	173		187
50	153		136	219		189
0	199		209	176		166
ARFR2						
100	3.7	**	31	17	**	57
50	12.3	**	19	21	**	51
0	12		23	31	**	81

Table 12. (continued).

	Sprayed		Unsprayed	
	Clipped	Unclipped	Clipped	Unclipped
VIAM				
100	.15	.07	6.7	5.2
50	.13	.60	3.5	3.5
0	1.2	1.1	5.6	4.3
MISC. FORBS				
100	6.5	1.1	40	68
50	3.6	24	50	97
0	8.5	5.3	44	48

* Means are significantly different at $P < .05$.

**Means are significantly different at $P < .025$.

[1] Application rate of N (lb./A).

Significant differences in production of AGSM and AGSP between clipped and unclipped plots were so scattered that one would suspect that it was pure chance that they showed up at all, and that no logical explanation can be given for their occurrence. Studies by Mueggler (1972) show that different degrees of competition strongly affect the degree of influence of clipping on AGSP. Clipping to ground level of all vegetation in addition to AGSP (as was done in this study) strongly reduces the effects of clipping on AGSP. Clipping-related differences in ARFR2 production occurred with all application rates of N, and on both sprayed and unsprayed sites (Table 12). Since these differences are highly significant and consistent, they must be genuine and indicate some detrimental effect of clipping on ARFR2. However, these results are different from results of the 1972 clipping study comparing productivities on grazed and ungrazed plots (Fig. 5) where grazing was shown to have increased yield of ARFR2. Apparently, the effects of grazing and clipping are not always the same (Costello and Turner 1941). As mentioned before, differences in degree of competition may have an effect on the degree of response of a species (ARFR2) to clipping.

Dry matter production on N-fertilized plots was much less in 1971 than in 1969 for all species except AGSP and miscellaneous forbs, regardless of spray treatment. The higher 1971 yield of miscellaneous forbs on the sprayed sites was due to the chance occurrence of a very large sweetclover plant in one of the plots, rendering insignificant the apparent large increase shown in Table 13. Between 1969 and 1971, relative increases in AGSP yield were greatest on unfertilized and unsprayed plots. The relative decrease of the other grasses was least on unsprayed plots given 100 lbs. N/A (Table 13). Yields of STCO2 and miscellaneous grasses increased slightly or remained the same on all unfertilized plots between 1969 and 1971 but decreased substantially on the N-fertilized plots.

Table 13. Ratios of dry matter production between years according to nitrogen application rates and spray treatment. (1971[1]/1969).

	Sprayed	Unsprayed
AGSM		
100[2]	.24[4]	.25
50	.36	.26
0	.43	.53
AGSP		
100	1.4	4.0
50	2.0	4.0
0	3.8	5.3
STCO2		
100	.40	.52
50	.53	.44
0	1.04	1.25
MISC. GRASS		
100	.24	.57
50	.34	.55
0	.97	1.29
TOTAL GRASSES		
100	.47	.66
50	.65	.63
0	1.23	1.34
ARFR2		
100	(-)[3]	.16
50	(-)	.20
0	(-)	.70
VIAM		
100	(-)	.60
50	(-)	.48
0	(-)	.31
MISC. FORBS		
100	.10	.63
50	2.76	.72
0	.41	.73
TOTAL FORBS		
100	2.9	.27
50	5.1	.38
0	2.2	.68

---

[1] Previously unclipped plots only.

[2] Pounds of N/A.

[3] Meaningful ratios impossible to calculate.

[4] Dry matter production of 1971 divided by 1969 dry matter production. Numbers considerably less than unity indicate a decrease between years, those greater than one indicate an increase.

A. smithii yield decreased significantly between years on all plots, with the greatest decrease on sprayed plots given 100 lb. N/A and the smallest decrease on unfertilized nonsprayed plots. In the case of AGSM, STCO2 and miscellaneous grass, the relative decline in production between 1969 and 1971 was much greater on the most heavily fertilized, sprayed plots and the relative increase in production of AGSP was much less on similar plots (Table 13). All of this strongly suggests that the effects of the added N in raising productivity rates above normal in 1969 diminished with time and were almost gone in 1971 since the declines for most species between years were greater on the more heavily fertilized plots.

Protection from grazing plus possible other factors between 1969 and 1971 resulted in a large shift in species composition (Fig. 8). The following discussion centers around the *relative contribution* of individual species to the total dry matter production of the community ARTR excluded), and must not be confused with discussions of *actual* lbs./A of production of these species.

The species shift in dry matter production between years on both sprayed and unsprayed plots was presumably due to the total withdrawal from grazing and/or possible weather differences. The data imply that past grazing pressure has maintained a disclimax with more AGSM and total forbs and less AGSP than would be found in a vegetation composition approximating the site potential.

In 1969 and 1971, on the sprayed plots, different application rates of N had no significant effect on the relative dry matter contribution of any species (Fig. 8). On the unsprayed plots, the 100 lb. N/A rate apparently caused a relative dry matter increase for ARFR2 (1969 only) and a possible decrease for miscellaneous forbs. These differences are slight and may not be significant (Fig. 8).

The percentage of total dry matter contributed by AGSM declined sharply between years on both sprayed and unsprayed sites (1971 data from previously clipped and unclipped plots were combined); that for STCO2, VIAM, and Miscellaneous Forbs remained essentially the same. The percentage of dry matter contributed by ARFR2 and total forbs increased between 1969 and 1971 on sprayed plots and decreased on unsprayed plots. The increase of forbs on the sprayed plots (Fig. 7) was due to recovery (mainly by ARFR2) from the herbicide treatment, whereas the relative decrease of forbs on unsprayed plots presumably resulted from the relative increase in total grass. Relative contribution of miscellaneous grasses to the total community dry matter production decreased between years on the sprayed plots and increased on the unsprayed plots. Why it did not increase on the sprayed plots as well as on the unsprayed ones is difficult to explain, although greater competition from recovering forbs on the sprayed plots may be at least part of the reason. The most spectacular change in percent dry matter contribution by a species was that for AGSP. On the sprayed plots, the relative dry matter production of AGSP went from an average of 16 percent in 1969 to an average of 52 percent in 1971, an increase of 325 percent; on the unsprayed plots the percent went from an average of 3 to an average of 19 between years, an increase of 634 percent. Relative contribution by total grasses to total production on sprayed plots decreased slightly (because of the recovery of forbs from the spray treatment) and increased considerably on the unsprayed plots due to the large increase by AGSP which more than counterbalanced the decrease of AGSM.

Effects of Treatments on Availability of Soil Nitrogen.

In an attempt to determine reasons for changes in CC, height, and yield of vegetation following chemical and mechanical treatments, data on N availability and soil moisture were gathered. Soil moisture changes are discussed in another section of the report.

Other studies in areas similar to central Montana indicated that crude protein content of some grasses, especially AGSM, varied directly with the availability of N in the soil (Houston et al. 1973, Rauzi et al. 1968, Smoliak 1965, Cosper and Thomas 1961, Rogler and Lorenz 1957 and Williams 1953). Their information suggested that variations in N-availability of soils from different sites and different types of treatments could be detected by collecting foliage of certain plant species and analyzing them for crude protein. Since AGSM was shown to have good correlation of crude protein with soil N-availability, was relatively common in the Yellow Water Triangle and Missouri Breaks study area, and was currently being studied, it was chosen to be sampled and analyzed for crude protein to determine if chemical and mechanical treatments increased soil N-availability.

Samples of AGSM were collected during the fertilizer study in 1969 and were analyzed for N, P, and K. Uptake of P and K were not correlated with fertilizer application or spray treatment, but different application rates of N were strongly correlated with percent N in AGSM foliage (Jorgensen 1970).

Assuming that increased N-availability in the soil is strongly correlated with increased N (or crude protein) in AGSM, it was decided to check for changes in soil N-availability following treatments by collecting AGSM foliage from these various areas and determining the N content.

Results based on samples collected from sprayed and control sites in 1969 were inconclusive (Fig. 10). Although the percent N in AGSM tissue collected from sprayed sites was higher than for tissue from adjacent control sites in every case, the only significant difference (5%) occurred on the Sibbert TKS area (Fig. 10). Perhaps a larger sample would have disclosed that all the differences between sprayed and control areas were significant.

Contour-furrowing (and presumably other mechanical treatments) definitely increased the availability of N in the soil, the difference still strongly evident nearly two years later (Fig. 10). These results are similar to those of Wight and Siddoway (1972) and Wight et al. (1974) who found that tillage increased N uptake as much as 58 percent for at least two years after treatment of sandy soils in southeastern Montana.

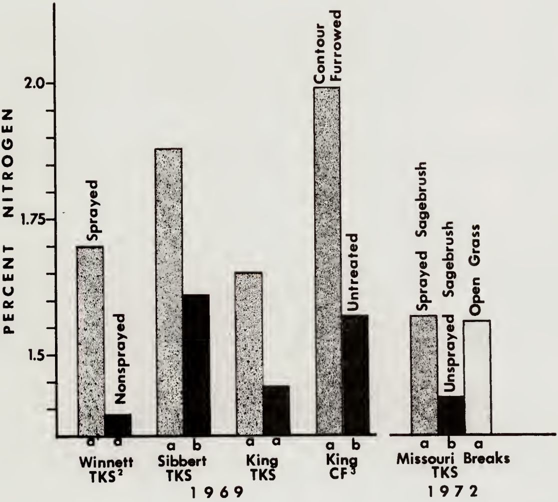


Figure 10 . Mean percent nitrogen in AGSM foliage from treated and control sites, Winnett, Sibbert, King, and Missouri Breaks study areas, 1969 and 1972.

[1] Different letters indicate significant differences
[2] Total kill spray
[3] Contour-furrowing

Such increased availability does not result from a greater amount of total N in the soil but is due instead to faster mineralization of organic matter already in the soil. This increased rate of mineralization (which converts plant-unavailable organic N to plant-available nitrates) (Houston and Adams 1971) is a consequence of better aeration and greater microbial activity following soil mixing.

Additional samples were collected in the Missouri Breaks in 1972 to ascertain the effects of spraying on available soil N (Fig. 10). The samples were collected about 2½ months after spraying; the percent crude protein figures conclusively demonstrated an increase in soil-available N the same year as treatment. Data are not available from subsequent years.

The evidence indicates that increased N-availability following treatments could be at least partially responsible for enhanced dry matter production as discussed previously.

SUMMARY AND CONCLUSIONS

As expected, the effects of partial kill spray treatment were much less pronounced and more difficult to measure than the effects of total kill spray. The only significant changes in canopy coverage following partial kills of sagebrush (50-80% live sagebrush remaining) were the decrease in live sagebrush and the increase in AGSM. Effects on forb CC were not noticeable. The significant differences resulting from PKS persisted for at least five years following application (Table 14).

Total kill spray treatments, applied to the Artemisia-Agropyron and Artemisia-rhizomatous Agropyron habitat types, effected a significant persistent increase in CC of AGSM and significant decrease in CC of forbs (mainly ARFR2 and VIAM) and sagebrush. The kill of sagebrush was generally between 95 and 100 percent. Unlike VIAM, the reduction of ARFR2 CC following spraying was short-lived, completely disappearing five years after treatment.

Increased dry matter production of AGSM, evident immediately after spraying, ranged from 1.13 to 3.16 times that of the controls, with little apparent correlation between the size of the increase and the intensity of kill or amount of time elapsed since treatment. In the Artemisia-Agropyron habitat type, dry matter production of AGSP, the dominant grass species, was 2.00 to 3.36 times higher on sprayed compared to unsprayed plots, and was still 2 times greater six years after treatment. Dry matter production of the two most abundant forb species, ARFR2 and VIAM was almost 100 percent less on sprayed plots compared to unsprayed plots one year after treatment. Six years after treatment, dry matter production of ARFR2 was 3.63 times higher on the sprayed sites than the controls; yield of VIAM on sprayed sites was still only 13 percent that of the controls. One year after spraying, dry matter production of STCO2 on the treated site was 3.75 times that of the controls, but after six years the ratio was down to 1.5. All other grasses

Table 14. Vegetation changes following treatment of sagebrush; comparisons of treated vs. control plots in the same year.

	Sagebrush-rhizomatous Wheatgrasses Total Kill				Sagebrush-bluebunch Wheatgrass Total Kill				Sagebrush-blue grama[1] Partial Kill				Mostly sagebrush-Bluebunch Wheatgrass Mechanical			
	1969	1971	1973	1974	1969	1971	1973	1974	1969	1971	1973	1974	1969	1971	1973	1974
CANOPY COVERAGE				[2]				[2]				[2]				[2]
Bare Ground	0	0	-		0	0	0		0	0	0		+++	++	++	
Grass	+	+	+		0	++	++		0	0	0		---	0	+	
Forbs	---	---	--		---	---	---		0	0	0		0	+	+	
SEDE	0	0	0		0	0	0		0	0	0		---	---	---	
LICH	0	0	0		0	0	++		0	0	0		--	--	--	
ARTR	---	---	---		---	---	---		--	--	--		0	0	0	
AGSM	++	++	++		++	++	++		++	++	++		++	++	++	
AGSP	NA	NA	NA		0	0	+		NA	NA	NA		-	-	-	
BOGR	NA	NA	NA		0	0	0		0	0	0		---	-	0	
STCO2	NA	NA	NA		0	0	0		0	0	0		--	--	0	
KOCR	0	0	0		0	0	0		0	0	0		0	+	+	
STVI	ID	ID	ID		ID	ID	ID		ID	ID	ID		+	++	++	
VIAM	--	--	--		--	--	--		0	0	0		0	0	0	
ARFR2	ID	ID	ID		---	---	0		0	0	0		0	0	0	
HEIGHT				[2]				[2]				[2]				[2]
ARTR	0	0	0		0	0	0		0	0	0		0	0	0	
AGSM	++	0	0		++	+	+		++	++	+		++	++	+	
AGSP	NA	NA	NA		0	0	0		NA	NA	NA		ID	ID	ID	
STCO2	NA	NA	NA		++	+	0		+	+	+		++	++	+	
KOCR	0	0	0		+	0	0		0	0	0		++	0	0	
STVI	0	0	0		ID	ID	ID		+	+	+		ID	ID	ID	
VIAM	0	0	0		0	0	0		+	0	0		+	0	+	
ARFR2	ID	ID	ID		0	0	0		0	0	0		0	0	0	
DRY MATTER PRODUCTION																
Grass	NM	NM	NM	NM	++	++	NM	NM					NM	NM	NM	NM
Forbs	NM	NM	NM	--	--	--	NM	NM					NM	NM	NM	NM
AGSM	NM	++	NM	++	++	++	NM	++					NM	NM	NM	++
AGSP	NM	NM	NM	NM	++	++	NM	++					NM	NM	NM	++
STCO2	NM	NM	NM	NM	+	0	NM	++					NM	NM	NM	0
KOCR	NM	NM	NM	NM	NM	NM	NM	0					NM	NM	NM	--
VIAM	NM	NM	NM	NM	--	--	NM	--					NM	NM	NM	0
ARFR2	NM	NM	NM	NM	--	--	NM	++					NM	NM	NM	++
TAOF	NM	NM.	NM	NM	NM	NM	NM	0					NM	NM	NM	0
Misc. Grass	NM	NM	NM	NM	0	++	NM	NM					NM	NM	NM	NM
Misc. Forbs	NM	NM	NM	NM	--	--	NM	NM					NM	NM	NM	NM

[1] Not measured for Dry Matter Production.

[2] Not measured in 1974.

+;- Increase or decrease significant at < .95.

++;-- Increase or decrease significant at > .95.

+++;---Very large increase or decrease significant at > .95.

ID Insufficient data to draw conclusions.

0 No change

NA Not applicable, species do not occur in these areas.

NM Not measured.

in this habitat type not discussed individually (lumped into the category of miscellaneous grasses), had a forage yield on the sprayed sites 1.61 times that of the controls after one year, but 1½ years later the situation was reversed with 1.1 times as much production on the control sites as compared to sprayed sites.

Mechanical treatments (contour-furrowing and interseeding) severely reduced the CC of SEDE and lichens for at least five years and the CC of BOGR and STCO2 for at least two years. In spite of increases in CC of AGSM and STVI after furrowing, the large decrease in BOGR CC was sufficient for a lower CC of total grasses through 1969. From 1971 on, there was a slight increase in total grass coverage on furrowed sites relative to control sites. The large increase in bare ground following treatment persisted for at least five years.

Dry matter yield of AGSP and AGSM on contour-furrowed plots after six years was 339 percent and 218 percent that of controls, respectively. Yield of STCO2 on furrowed plots was similar to that of the controls, whereas yield of KOCR on furrowed plots was only 30 percent that of the controls. The effects of mechanical treatment on various species of grass obviously are different and don't seem to be related to the principle means of reproduction. Seed reproducers are found both in the group of grasses aided by furrowing and in the group damaged by furrowing.

Hypothetically, differences in yield of grasses following treatment could be at least partially related to differences in grazing pressure. Yield of ARFR2 on furrowed plots, six years after treatment, was about double that of controls but was about the same for TAOF and VIAM. A larger increase in CC and yield of forbs, which often occurs following severe land disturbances, did not materialize. Canopy coverage and height data do not indicate significant increases in sagebrush after furrowing in spite of the general visual impressions to the contrary.

Some significant short-term effects on foliage height of grasses were noted following chemical and mechanical treatments. Contour-furrowing caused increases in height lasting for at least one year for KOCR and up to three years for AGSM and STCO2. Such height increases raise the dry matter yield of individual plants but not necessarily the yield over an extended area, particularly if basal area and canopy coverage have been reduced. Spraying increased the foliage height of only AGSM, and this was for a relatively short period of time.

Six years after both TKS and contour-furrowing treatments on the King SA, ratios of water to dry matter in tissues (succulence) of ARFR2 and VIAM were less on treated areas. Water content of TAOF was unaffected. It is unknown whether the decrease in succulence was due to reduced water retention in the cell sap of the plants, or to the increase of some plant material in relation to the amount of water. The ecological importance of such treatment-related reduced water content in some forbs can only be speculated.

The study of combined fertilizer-herbicide effects showed that in the Artemisia-Agropyron habitat type, the increased yields resulting from application of up to 100 lbs. of N/A were short-lived for all herbaceous species. The effects on sagebrush are not known. Applications of phosphorus had no effect on yield, either because levels of this nutrient are not limiting or because applications of the nutrient were made unavailable by the soil.

The correlation between N-application rates and 1969 (year of application) AGSM dry matter yield was high on both sprayed and nonsprayed plots. The 50 lbs. N/A rate produced less yield than the 100 lbs N/A rate, and the 0 lbs. N/A rate produced less yield than the 50 lbs N/A rate. For AGSP, STCO2, and miscellaneous grasses, differences in yield depended on whether N was applied or not, with no significant difference in yield of these species at the 50 or 100 lbs. N/A rates. No significant N-related differences in yield of these species were noted on the unsprayed plots. The only forb whose yield was influenced by N application was ARFR2. The differences in yield were found only on the unsprayed plots and were correlated only with whether N was added or not. In 1971, no fertilizer-related differences in yield existed. In view of this, applications of commercial N at rates up to 100 lbs./A to rangelands in this habitat type are far from justifiable. In 1969, the effects of N-application and spraying on grass productivity appeared to be synergistic, but by 1971 the effects of spray treatment were the only ones present.

On all plots, sprayed or unsprayed, fertilized or unfertilized, significant shifts in floristic composition occurred between 1969 and 1971. The greatest changes were the large increase in yield of AGSP and the decrease in yield of AGSM, both occurring regardless of the type of spray or fertilizer treatment applied, and whether or not they had been clipped in 1969. Complete protection from grazing appears to be causing a rapid return to the potential vegetation association of the habitat type.

A search for causes of the changes in species canopy coverage, vigor, and dry matter production after chemical and mechanical treatments led to an examination of changes in soil moisture and available soil N following treatments. It was found that a definite but apparently short-lived increase in mineralized N occurs after an area is sprayed for total kill of sagebrush, and that a larger and possibly longer-lasting increase in mineralized N occurs after contour-furrowing and interseeding. These increases in mineralized N do not represent increases in total nitrogen existing in the ecosystem, but rather are results of conversion of plant-unavailable organic N to a form that can be utilized. Indeed, once the mineralized N that was made available by treatment is removed from the ecosystem (in the form of livestock protein), the total N levels will probably be lower than before treatment. No treatment-related effects on levels of available phosphorus or potassium could be shown. In the soil moisture study, significant increases in available soil moisture occurred following total kill spraying, but could not be shown following mechanical treatment or partial kill spraying.

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JOB NO.: V-1.5

Sub-job title: Effects of treatments on soil moisture.

INTRODUCTION:

Various studies of the effects of chemical removal of big sagebrush have documented indirect changes in associated vegetation following such treatment (Thilenius and Brown 1974, Hyder and Sneva 1956, Cornelius and Graham 1958, Blaisdell and Mueggler 1956, and Mueggler and Blaisdell (1958). Generally, postreatment changes involved increases in graminoid canopy coverage and yield. A common conclusion based on such results is that removal of sagebrush from a plant community frees a certain amount of soil moisture to be utilized by vegetation not killed by the herbicide.

Evidence indicates, however, that the situation may not be that simple. Studies by Hyder and Sneva (1956) and Fisser (1968) showed more rapid depletion of soil moisture on sprayed areas. There is the possibility that grass more effectively depletes soil moisture than do shrubs (Prill 1965) and that conversion of a sagebrush-grassland to pure grassland could result in greater withdrawal of moisture than before.

Sagebrush may extract much of its moisture from greater depths in the soil than do herbaceous plants. Studies in Wyoming by Tabler (1968) and Sturges (1973) of widely varying sagebrush habitat types showed herbicide treatment of sagebrush ranges resulted in a greater reduction of moisture withdrawal deep in the soil than at shallower depths, possibly due to the death of deep sagebrush roots. Hedrick, et al. (1966) found that moisture was greater on treated plots in Central Oregon until deeprooted species increased substantially.

The philosophy behind mechanical treatment is that heavy surface water runoff is slowed, allowing more of it to penetrate the soil (Hubbard & Smoliak 1953). Change in vegetation structure, such as removal of *Selaginella densa,* (clubmoss) may also be an objective (Ryerson, et al. 1970, Dolan et al. 1972). Some studies indicated that mechanical treatments (generally contour-furrowing or pitting) caused at least some increase in soil moisture. Results of Branson et al. (1962) in northeastern Montana show 8 percent more soil moisture in heavy clay soils following treatment. Houston (1965) found that pitting increased soil moisture on fine-textured but not on coarse-textured soil. Wight, et al. (1974), working on sandy soils in eastern Montana, concluded that the only mechanical treatment causing increased soil water recharge was lister interseeding. Branson, et al. (1966) stated that storage capacity of mechanically treated areas decreased rapidly in the first 5 years.

To help determine the causes and nature of vegetational changes following herbicide and mechanical treatments of sagebrush rangeland, a soil moisture study of treated sites in the Yellow Water Triangle was initiated during fall 1968. A more intensive study began in the Missouri River Breaks in 1972.

This study attempted to ascertain whether or not there was a difference in soil moisture withdrawal at different soil depths between treated and untreated sagebrush-grasslands, and to determine the effect of treatments on soil moisture recharge and depletion in the Yellow Water Triangle area.

METHODS

Description of sites

In 1968, soil moisture monitoring stations were established on 7 sites in the Yellow Water Triangle. Comparisons to be made were: sprayed sagebrush (sprayed in early summer 1968) vs. nonsprayed sagebrush; mechanically-treated vs. untreated; and sagebrush-grassland vs. open grassland. Grazing was deferred for at least 1 year following treatment on all sites. Locations and station numbers (Yellow Water Triangle) are as follows: (Fig. A, B, and C)

			Grazing deferment-years
Iverson study area	1a.	Spray strip (partial kill) vs.	4
	1b.	Leave strip;	4
	2a.	Partial kill area vs.	4
	2b.	Leave area;	4
King study area-	3a.	Interseeded vs.	4
	3b.	Open grass untreated and	4
	3c.	Sagebrush untreated;	4
	4a.	Contour furrowed vs.	4
	4b.	Untreated;	4
Winnett study area-	5a.	Dense sagebrush vs.	1
	5b.	Open grass;	1
	6a.	Spray strip (exclosure) vs.	4
	6b.	Leave strip (exclosure);	4
	7a.	Spray strip vs.	1
	7b.	Leave strip.	1

Detailed descriptions (done by SCS in 1968 and 1970) of the soil types at each location are included in the appendix of this report; pertinent soils information is presented in Table 1.

Table 1. Soil Data from soil moisture monitoring station locations.

Station	Soil name[1]	Depth	Texture[1]	Bulk Density[2]	Water holding Capacity[3]	Per-cent at FC[4]	Per-cent at PWP[5]
1	Drag CL	6"	CL	1.49	1.05	27	15
		12"	C	1.56	1.15	31	18
		24"	C	1.66	1.35	31	17
		36"	C	1.62	1.25	28	15
		48"	C	--	--	27	16
2	Woodhawk CL	6"	CL-C	1.50	1.25	33	19
		12"	C	1.53	1.15	28	16
		24"	C	1.68	1.35	29	16
		36"	C	1.75	1.40	30	16
		48"	SiCl	1.70	1.30	27	14
3	Abor SiC	6"	SiCl-SiC	1.76	1.18	29	17
		12"	SiC	1.81	1.27	28	17
		24"	SiC	1.79	1.32	30	18
		36"	SiC-shale	--	--	29	17
		48"	SiC-shale	--	--	31	18
4	Bercail CL	6"	CL-C	1.64	1.08	27	16
		12"	C	1.74	1.14	23	13
		24"	SCL	1.86	1.19	21	10
		36"	C	--	--	21	10
		48"	C	--	--	19	10
5	Marias SiC	6"	SiC-C	1.32	.90	30	18
		12"	C	1.51	1.10	31	18
		24"	C	1.57	1.55	36	20
		36"	C	--	--	31	18
		48"	C	--	--	28	17
6	Thebo C	6"	CL-C	--	est 1.7	31	18
		12"	C	--	est 1.7	31	17
		24"	C	--	est 1.0	30	18
		36"	C shale	--	--	31	19
		48"	C shale	--	--	32	18
7	Syblon SiL	6"	SiL	1.62	.85	16	7
		12"	SiC	1.62	.90	17	9
		24"	CL	1.78	1.10	19	9
		36")	shale &	--	--	18	10
		48")	silt stone	--	--	18	10

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[1] Texture abbreviations: C-clay; L-loam; Si-silt; S-sand.

[2] Bulk density (BD) density of an intact (unbroken) soil sample compared to water (water=1.0).

[3] Inches of plant-available water per 1/2 foot of soil.

[4] Soil moisture percentage (by weight) at field capacity (% of water left after excess has drained away by gravity).

[5] Soil moisture percentage (by weight) at permanent wilting point (% of water at which plants become permanently wilted without addition of more water).

-- Not determined.

In June 1972, a more intensive study of soil moisture was initiated on treated sites (sprayed in May 1972) in the Missouri Breaks study area. Monitoring stations were established in sprayed sagebrush, unsprayed sagebrush, and open grass with homogeneous soil throughout. None of the treatment sites were grazed by cattle during the period, but some light use by elk was noted in 1973 and 1974. Soil is a Thebo clay with the following characteristics:

Texture	Depth	Bulk Density	Estimated Water-holding Capacity	Percent at FC	Percent at PWP
C	6"	1.77	1.7	39 (est.)	23
C	9"	1.92	1.8	39	23
C	12"	1.82	1.7	39 (est.)	23
C	18"	1.79	1.7	39	23
C w/shale	24"	1.51	.9-1.3	25-35	15-20

Technique

Soil moisture potential (a measure of how tightly the water is held by the soil) was measured using Bouyoucos gypsum blocks. The blocks were installed in stacks of five, one block at each depth. In the Yellow Water Triangle, the depths were 6 inches, 12 inches, 24 inches, 36 inches and 48 inches. In the Missouri Breaks the depths were 6 inches, 9 inches, 12 inches, 18 inches and 24 inches. Duplicate stacks were installed for each treatment at each site in the Yellow Water Triangle, whereas seven stacks were installed for each treatment in the Missouri Breaks study area.

Calibration of soil samples (taken from around each soil block as it was installed) was accomplished using the method of Bouyoucos and Mick (1940). Soil temperature was measured at each time of soil moisture monitoring, (using thermistors buried at the same depths as the gypsum blocks) so that temperature corrections could be incorporated into the calibration process.

Readings were taken at somewhat varying intervals with an attempt made to take them at two week intervals in the Yellow Water Triangle and at one-week intervals in the Missouri Breaks; lack of time prevented this during many periods. Most readings were taken during late spring and summer, none in winter.

In some years a considerable portion of the soil moisture recharge in the Yellow Water Triangle area comes from melting snow. Distribution of snow cover in the region is highly influenced by wind; snow accumulating in heavy sagebrush stands at the expense of open grassy areas. During the winter of 1971-72, measurements were made of snow depth to compare water content in and out of sagebrush stands, and to determine if spray treatment of sagebrush affected snow accumulations. Snow depths were measured above each moisture block to correlate soil moisture recharge with variations in snow depth.

Precipitation at each of the soil moisture monitoring sites was measured using ground-level storage gauges installed in summer 1968. These gauges were checked approximately monthly during the warm season. Winter precipitation was measured as a total for the entire season. Since these gauges probably do not accurately measure snowfall precipitation, winter precipitation figures are unreliable. Further inaccuracy may have resulted from the fact that none of the rain gauges was provided with wind shields, although the detrimental effects of wind on rain gauge accuracy presumably are less than for standard unshielded rain gauges whose openings are several feet above the ground.

Precipitation measurements were compared with soil moisture measurements. Dry matter production of *Agropyron smithii* on the Missouri Breaks study site was measured in 1972 and 1974. In addition, dry matter production of forbs was measured in 1974. Canopy coverages and heights of all species were estimated in 1974 using 40 randomly-located 2 X 5 dm. plots per treatment site.

RESULTS AND DISCUSSION

Soil moisture percentages, of course, were strongly related to precipitation with changes in the upper levels of the soil more closely tied to periods of precipitation than those at greater depths. Since moisture requires time to penetrate to greater depths, an increase in moisture percentage may not become evident until several days after a storm; drying out of these lower layers may require weeks compared to days for upper layers. This can be seen on accompanying graphs of soil moisture trends (Fig. 1, 2, 3, 4, 5, and 7).

Soil Moisture Recharge

The depth to which water from a particular storm will penetrate depends on a number of factors. One of these, constant for a given soil, is the water-holding capacity (Table 1). The greater the water-holding capacity in upper levels, the greater will be the amount of water needed to penetrate to lower levels. Other factors affecting penetration depth of a given amount of precipitation into level soil are antecedent moisture (how much moisture was already in the soil before the storm), rainfall intensity, degree and type of vegetal cover, amount of litter, and surface roughness. The latter three could be influenced by the various range treatment practices under consideration in this study. I assume that relatively high coverages of vegetation and litter and a rough surface (such as that resulting from contour-furrowing) would assist the infiltration of water into the soil.

Results of another study on this project indicate an increase in grass canopy coverage resulting from partial kill spray treatments in the Yellow Water Triangle probably was not great enough to offset the loss in canopy coverage provided by shrubs and forbs.
Changes in litter cover were highly inconsistent with no significant increase due to spraying. Because the effects of spraying on these factors influencing moisture penetration are unclear, one might suspect that the spray treatment in the Yellow Water Triangle would have had little effect on moisture penetration. Indeed, data indicate that to a certain extent this was the case.

Recharge of soil moisture following storms was not significantly different except at 3 and 4 ft. levels when comparing sprayed and unsprayed sites on the Winnett and Iverson study areas (Fig. 1 and 2). If shallow layers of a soil under one treatment (nonspray) become drier than those layers under another treatment (spray) due to greater depletion of moisture by vegetation, this will decrease antecedent moisture, reducing the depth of water penetration from subsequent storms.

The total kill spray treatment in the Missouri Breaks produced significant changes in bare ground, grass, live shrubs, and litter still evident in 1974 (Table 2).

Table 2. Percent canopy coverage for sprayed sagebrush, unsprayed sagebrush, and grass sites in the Missouri Breaks, 1974.

	Sprayed	Unsprayed	Grass
Bare ground	9	26	16
Grass	61	30	39
Forbs	1	2	25
Shrubs	0	17	0
Mulch	59	41	52
Standing litter	54	22	9

In the Missouri Breaks (Fig. 6) soil moisture at the end of winter and immediately following heavy summer rainstorms (periods following recharge but before depletion) was not significantly different on the unsprayed site than it was on the sprayed site.

Differences (significant at $P < .025$) in soil moisture percentage on Yellow Water Triangle treatment sites were evident mostly at the four-foot depth (Fig. 1 and 2). This indicates (for soils and vegetation of the Yellow Water Triangle area) that the death of sagebrush roots may have effected increased recharge of moisture at four-feet during a year when water was able to penetrate that far. Data of 1970 (Fig. 1 and 2) show that this was the last year, before Yellow Water Triangle measurements were discontinued (1972), that the entire profile was saturated (all pore space filled with water). Moisture in subsequent years did not penetrate beyond 2 feet (indicated by a lack of sharp rises in moisture level at depths below 24 inches in 1971 and 1972 - Fig. 1 and 2), implying that moisture present during this time at 4 feet apparently came during some previous time (1970 and before), and that differences in moisture percentage at this depth reflect differences in penetration during 1970 (and possibly 1968). In 1970, replenishment of moisture at the three-foot depth was greater on the sprayed than the unsprayed sites, while at the four-foot depth some recharge occurred on the sprayed sites but not on the unsprayed sites. By late 1970, soil moisture was almost completely (and equally) removed from all sites at the three-foot level; this condition remaining unchanged through 1972. A similar situation was present at four-feet. The moisture difference between treatments established in 1970 (and possibly earlier) persisted through 1972.

Soil Moisture Withdrawal

Significant differences in moisture withdrawal from Yellow Water Triangle soils could not be detected, possibly due to inadequacies in sample size. However, in the Missouri Breaks study area, highly significant differences in withdrawal rates were evident (Fig. 5).

During 1972 the soil of the sprayed site (Missouri Breaks) had more moisture in it than the other sites at all depths above 2 feet. Although 1972 dry matter production of grass on the sprayed plot was not significantly higher than on the open grass plot (Table 3), soil moisture withdrawal was less, implying perhaps that the "green-manuring" effect resulting from the death of sagebrush increased the efficiency of water use by the grass. Moisture levels of soils on unsprayed sagebrush and open grass sites remained virtually the same except at 2 feet. A significant increase in soil moisture in the upper 12 inches on the sprayed site relative to the other two sites began to appear in July 1972. By the end of the season moisture was exhausted in the soils of all treatments at all levels. The depletion curve at 2 feet suggests that

Table 3. Mean air-dry weight (kg./ha). Missouri Breaks treatment area 1972 and 1974.

		Site		
		Sprayed Sagebrush	Unsprayed Sagebrush	Grass
Grass (AGSM)	1972	191a	110b	189a
	1974	698a[1]	379b	478b
Forbs	1974	0a	26b	129c

[1] Means in the same row followed by the same letter are not significantly different at $P < .01$.

the effects of the spray treatment were not felt at this depth in any year. The fact that moisture at 2 feet for both sagebrush sites remained the same throughout 1972 may indicate that sagebrush roots do not effectively remove water from below 18" in this kind of soil. The soil under open grass was dry at 12, 18, and 24 inches most of 1972, not because of depletion of moisture by grass, (since the bulk of grass roots *(Agropyron smithii)* at this site is above 20 cm (about 8 inches) (Jorgensen 1970) but because of a lack of recharge at the beginning of the season.

In 1973, as in 1972, soil moisture was greater in the upper 18" of the sprayed site than in soils of the other two sites except at the beginning and end of the season. A considerable difference in soil moisture between the unsprayed sagebrush site and the open grass site was evident for all depths below six inches. This difference, not evident in 1972 or 1974, may possibly be explained by variations in snow accumulation between sites. A heavy snowfall and accumulation occurred in April 1973 but not in other years. Data from the Yellow Water Triangle (Fig. 6) demonstrate that wind removes snow from open areas and deposits it in stands of sagebrush. Consequently the water content of snow on sagebrush sites at the end of the season may be as much as three times that on open grass sites. If this occurred in the Missouri Breaks, it could explain why the unsprayed (and sprayed) sagebrush sites started out with much more moisture than the open grass site in 1973 but not in 1972 and 1974. The two sagebrush sites would tend to accumulate similar amounts of snow (data indicate that snow accumulations in sprayed and unsprayed sagebrush are equal) (Fig. 6), producing similar moisture levels early in the season, but faster withdrawal would dry out the unsprayed site more quickly.

The extremely wet conditions of 1974 resulted in soil moisture levels remaining above the permanent wilting point for a large part of the growing season on all treatment sites and at all depths. The apparent large difference in moisture between treatments early in 1974 at all levels (Fig. 5) is not significant due to large within-treatment variability. Moisture conditions at all sites were similar until heavy withdrawal began to deplete the moisture in about mid-June. All moisture differences from mid-June until mid-July can be assumed to result from differences in withdrawal rates since all soils started with the same condition in early June, i.e. saturation at all depths. In mid-July, all soils were once again saturated, so differences in moisture levels occurring after that period were again due to differences in withdrawal rates.

Figure 5 shows a greater rate of removal of water from the 12, 18, and 24 inch depths of the unsprayed sagebrush site than from either of the other two sites. Presumably this is because of the presence of active sagebrush roots at these depths on the unsprayed sagebrush site and the absence of roots at the same depths on the other sites.

Death of sagebrush roots relatively near the surface would indeed reduce competition for moisture between herbaceous plants and shrubs, but any moisture in excess of that usable by the heaviest possible stand of herbaceous plants probably penetrates below the working zone of such roots and therefore becomes unavailable for use by vegetation at the site. In central eastern Montana such moisture occurs once every few years. Shrub roots at greater depths presumably would consume most or all of the water penetrating below the bulk of grass and forb roots. In this way, a community comprising both shrubs and herbaceous plants could more thoroughly utilize available moisture than one consisting solely of shallow-rooted herbaceous plants. Because of this, a community comprising both sagebrush and herbaceous plants may possess greater total productivity than one situated on a similar site consisting solely of grass, especially if sagebrush is using deep moisture at times of the year when shallow moisture is unavailable (Daubenmire 1970). By 1974 (2½ years after spraying) the canopy coverage and dry matter production of grass on the sprayed site was greater than that of the open grass site but production of forbs was much less (Tables 2 and 3). Demands of herbaceous plants for moisture apparently produced similar moisture depletion patterns for those two soils at depths below nine inches. At 6 and 9 inches, however, depletion of moisture was significantly greater on the grass site than the sprayed sagebrush site and may suggest that forbs deplete soil moisture more rapidly than grass at very shallow depths.

Effect of Mechanical Treatment on Soil Moisture (Fig. 7)

Data do not show that soil moisture conditions were significantly different on treated compared to untreated sites. Such treatments (generally done on slopes) theoretically enhance the permeability of soils, reducing runoffs from snowmelt and high intensity summer rainstorms. This, in turn, should increase the amount of water entering the soil, improving soil moisture conditions. Rauzi et al. (1962) in Wyoming, found that infiltration of moisture into soil was increased substantially by pitting.

Although other studies have shown increases in soil moisture following mechanical treatments (Branson et al. 1962, Houston 1965, and Wight et al. 1974), it may not be safe to assume that such is always the case. This study indicates that mechanical treatment where it was done had no measurable effect on soil moisture. If there was an actual increase in soil moisture not detected by this study, an explanation is the possibility that there were not enough high runoff conditions during the period to make any difference in moisture recharge. Slight increases in moisture recharge in the upper layers (6" and less) of soil might be negated by increased evaporation resulting from greater surface area of the furrowed soil (Wight, et al. 1972). Canopy coverage of vegetation was not increased sufficiently to account for utilization of any possible extra moisture made available by the treatment, although Wight et al. (1972) hypothesize that increases in soil moisture following mechanical treatments would be used by increased vegetation growth, making them difficult or impossible to detect. Another possible explanation could have been an insufficient sample size. Considering the high variability of these soils, the number of blocks probably should have been much greater.

CONCLUSIONS:

Both herbicide and mechanical treatments had little effect on the soil moisture regime of those Yellow Water Triangle (YWT) soils where studies were conducted. Spraying of sagebrush apparently caused a slight increase in soil moisture recharge at the four-foot depth. This increase in moisture persisted from 1970 through 1972 when measurements were discontinued. A variety of reasons may explain the lack of soil moisture response to treatments, the most important of these being that the treatments as they were performed in the YWT did not strongly influence factors which in turn affect soil moisture. All soil moisture testing in the YWT, where effects of spray treatments were being compared, was done on partial-kill areas. On these areas, the kill of sagebrush was generally not more than 50 percent and often much less, with the result that accompanying changes in associated vegetation and soil moisture were slight and difficult to measure. Mechanical treatment could not be shown to have had any effect on the soil moisture regime, although this is not to say that changes could not be demonstrated with larger sample size or if the experiment was conducted on a different soil, such as one more prone to runoff problems.

Results of the experiment conducted in the Missouri Breaks study area, different from those above, point to a very distinct change in soil moisture regime following treatment. In contrast to those spray treatments applied in the YWT, the treatment used here was a spray for total kill of sagebrush. In addition to changes in live vegetation, the spray treatment produced a large significant decrease in bare ground and a significant increase in mulch (flat litter). Soil moisture depletion was shown to be significantly less on the sprayed site than the unsprayed sagebrush and open grass sites from one month after treatment until two and one-half years after treatment when measurements were discontinued. The open grass site was driest in 1972, possibly because of a difference in snow accumulation the preceding winter. Snow in windy areas such as central Montana tends to be blown off sagebrush-free areas and deposited in stands of sagebrush. Such differential accumulations of snow have a profound influence on the soil moisture regime during the following spring. Removal of sagebrush from flat windy areas will surely have an effect on the recharge of soil moisture and be detrimental to those plants depending on a good supply of water in early spring.

The effect of sagebrush roots on soil moisture depletion apparently was greatest from 12" down, whereas the effects of grass roots were greatest from 9" upward. The presence of sagebrush roots to withdraw deep moisture presumably enables the plant community to make greater use of available water resources than if only relatively shallow-rooted grasses were present. A large part of the water entering the soil during a wet year like 1974 cannot be utilized by herbaceous vegetation, allowing it to pass through the profile. A much larger proportion of that water can be used for dry matter production in the community if sagebrush is present with roots extending down 2 feet and more.

Effects of changes in bare ground and litter are difficult to isolate from effects of changes in living plants themselves. Presumably these physical surface characteristics would have more influence on deep soil moisture recharge than on withdrawal. Evaporation, as opposed to removal of moisture by plants from soil depths of 6 inches or less (evaporation of moisture generally is not important at depths below 6 inches in most soils), could conceivably be slowed by a heavy cover of mulch. However, if grazing is allowed following spray treatment, such litter accumulations and concurrent reductions in bare ground would be diminished.

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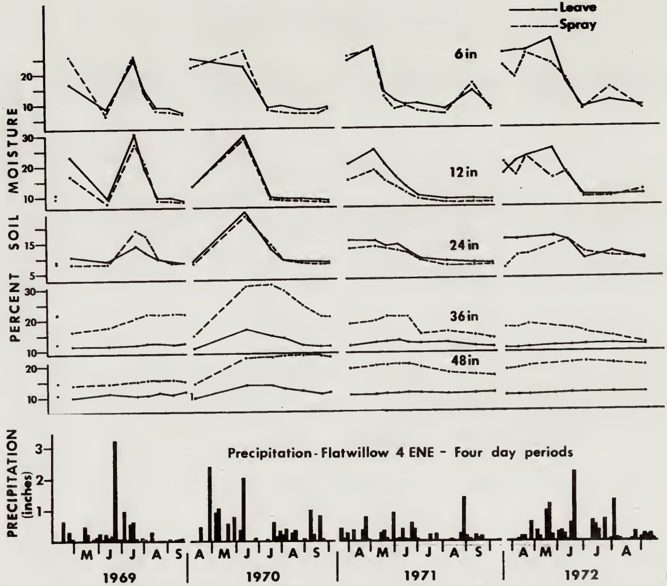

Figure 1. Mean soil moisture beneath sprayed and unsprayed strips. Stations 6a and 7a vs. 6b and 7b. Winnett study area.

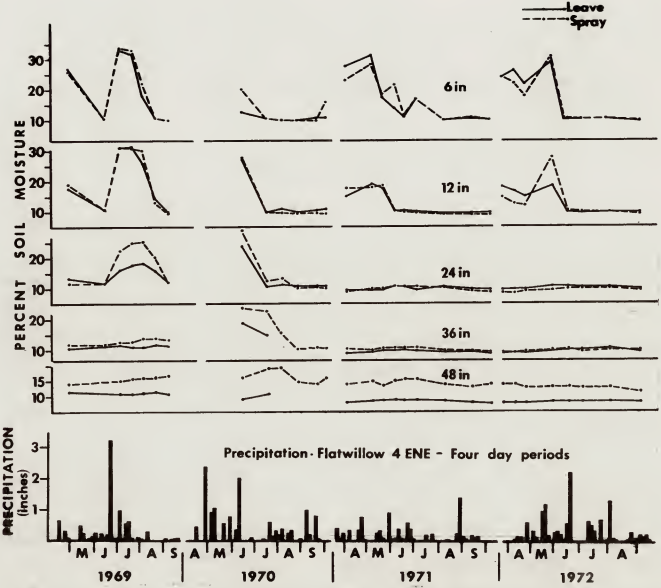

Figure 2. Mean soil moisture on sprayed and unsprayed sites. Sagebrush-Blue grama vegetation type. Stations 1a & 2a vs. 1b & 2b. Iverson study area.

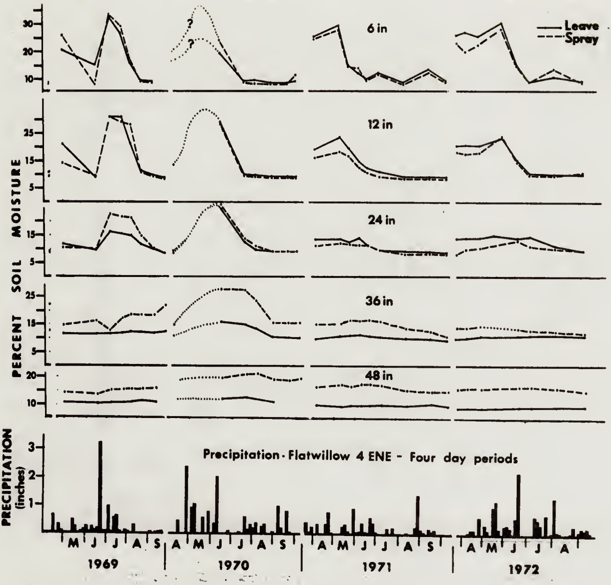

Figure 3. Mean soil moisture beneath sprayed and unsprayed sites. Stations 1a,2a,6a,& 7a vs. 1b,2b,6b,& 7b. Winnett and Iverson study areas. Dotted lines signify estimated curves.

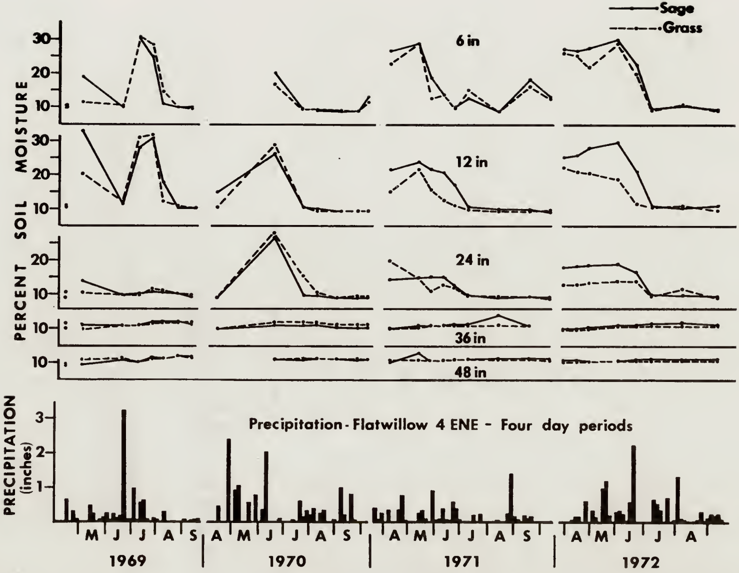

Figure 4. Mean Soil moisture on adjacent sagebrush and open grass sites. Stations 3b & 5b vs. 3c and 5a. Winnett and King study areas.

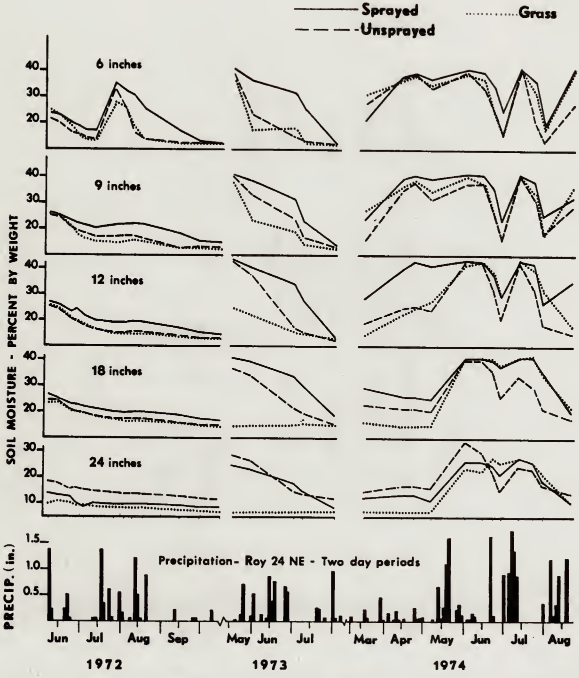

Figure 5. Mean soil moisture on sprayed sagebrush, unsprayed sagebrush, and open grass sites. Missouri Breaks study area.

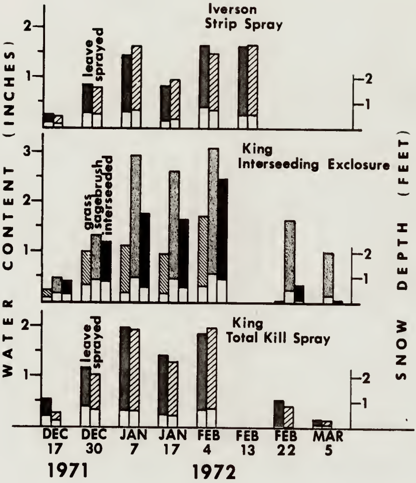

Figure 6. Depth and moisture content of snow. Yellow Water Triangle 1971-1972. Unshaded section of each bar is snow depth.

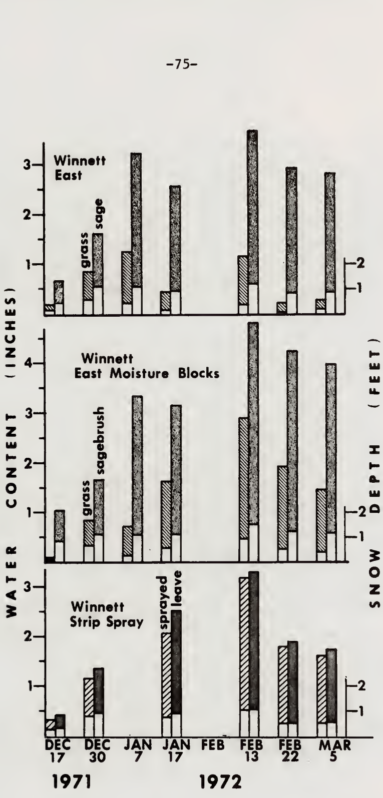

Figure 6. (continued)

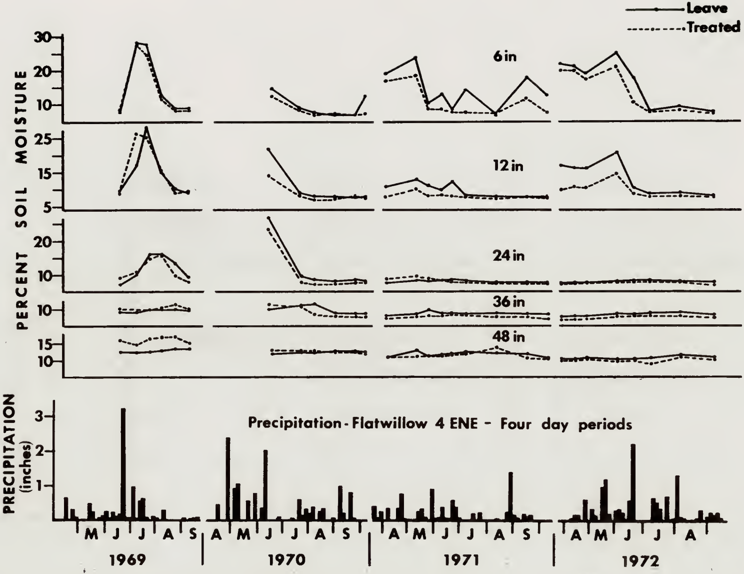

Figure 7. Mean soil moisture on mechanically-treated vs. control sites. Stations 3a & 4a vs. 3b,3c, & 4b. King study area.

APPENDIX

Soil Description No. 1

IVERSON STRIP SPRAY

Soil Type: Drag clay loam.
Area: Petroleum County.
Date: November 25, 1969.
Classification: Fine, mixed frigid family of Mollic Natrargids.
Location: In NW¼SW¼ of Section 12, T 12N, R25E.
Vegetation: Big sagebrush, crested wheatgrass, western wheatgrass and green needlegrass.
Parent Material: Clay alluvium.
Physiography: High Bench.
Relief: Smooth.
Elevation: 3100 feet.
Slope: 1 percent.
Aspect: Southeast.
Erosion: None.
Permeability: Slow.
Drainage: Well drained.
Gr. Water: Very deep.
Moisture: Slightly moist to 6 inches -- dry below.
Root distribution: Many to 5 inches -- common to 7 inches.

Additional Notes: There is 50 to 60 percent clay in B2T horizons and about 5 percent less in the B3 and C horizons.

Pedon Description: Drag clay loam.

A21 0-3" Light brownish-gray (10YR 6/2 tops of plates and 5/2 bottoms of plates, and 6/2 rubbed) light clay loam, dark grayish-brown (10YR 4/2) moist; strong fine plates that separate to strong fine granules; slightly hard, friable, slightly sticky and slightly plastic; many fine pores and roots; clear lower boundary.

A22 3-5" Light brownish-gray (10YR 6/2) clay loam, dark brown (10YR 3/3) moist; weak medium plates that separate to weak medium and fine subangular blocks; hard, friable, sticky and plastic; many bleached silt and sand grains; many fine and very fine roots and pores; abrupt lower boundary.

B21t 5-7" Grayish-brown (10YR 5/2) clay, dark brown (10YR 3/2) moist; moderate medium columnar structure: extremely hard, firm, sticky and very plastic; thick continuous clay films on peds; reaction pH 8.4; common very fine pores and common very fine roots; clear lower boundary.

B22t 7-17" Grayish-brown (10YR 5/2) clay, dark grayish-brown (10YR 4/2) moist; moderate medium prisms that separate to moderate medium and coarse subangular blocks; extremely hard, firm, sticky and very plastic; no effervescence in upper 2 inches; moderate effervescence below; pH 8.6; distinct horizontal pressure faces; continuous clay films on peds; common fine and very fine pores; few roots following seams; clear lower boundary.

Soil Description No. 1 (continued).

B23t 17-24" Grayish-brown (10YR 5/2) clay, dark grayish-brown (1Y 4/2) moist; moderate medium and coarse prisms that separate to moderate coarse subangular blocks; extremely hard, firm, sticky and very plastic; moderate effervescence; few films and small masses of lime; pH 8.6 distinct horizontal pressure faces; common fine and very fine pores; common very fine roots, clear lower boundary.

B3 24-32" Grayish-brown (10YR 5/2) clay, very dark grayish-brown (2.5Y 3/2 unrubbed and 10YR 3/1 rubbed) moist; weak medium prisms that separate to weak medium and coarse subangular blocks; extremely hard, firm, sticky and very plastic; moderate effervescence and few films of lime; common fine and very fine pores; common fine and very fine roots; clear lower boundary.

C1Cs 32-46" Marbeled light yellowish-brown and dark gray (10YR 6/4 and 4/1) clay, marbeled yellowish-brown and very dark gray (10YR 5/4 and 3/1) moist; massive; hard, friable, sticky and very plastic; moderate effervescence; few very fine pores and roots; clear lower boundary.

Soil Description No. 2

IVERSON PARTIAL KILL

Soil Type: Woodhawk clay loam.
Area: Petroleum County. Date: November 25, 1969.
Classification: Fine, mixed, frigid family of Abruptic Aridic Argiborolls.
Location: In NE¼SE¼ Section 12, T 12N, R25E.
Vegetation: Big sagebrush, western wheatgrass, bluegrasses.
Parent Material: Clay alluvium.
Physiography: Old high bench.
Relief: Smooth.
Elevation: 3100 feet. Drainage: Well drained.
Slope: 1 percent. Gr. Water: Very Deep.
Aspect: South. Moisture: Dry throughout.
Erosion: None. Root Distribution: Many to 22 inches -- common to 38" and few below.
Permeability: Slow.

Pedon Description: Woodhawk clay loam.

A1 0-3" Grayish-brown (2.5Y 5/2) clay loam, very dark grayish brown (2.5Y 3/2) moist; weak fine plates that separate to strong fine granules; slightly hard, friable, slightly sticky and slightly plastic; many bleached silt and sand grains; many fine and very fine roots; abrupt lower boundary.

B21t 3-8" Brown (10YR 4/3) clay, brown (10YR 4/3 rubbed and 3/3 unrubbed) moist; moderate medium prisms that separate to strong, very fine, subangular blocks; thick continuous clay films; very hard, firm, sticky and very plastic; many fine and very fine roots; many fine and very fine pores; clear lower boundary.

B22t 8-14" Grayish-brown (1Y 5/2) clay, dark grayish-brown (1Y 4/2 rubbed and 3/2 unrubbed) moist; strong medium prisms that separate to strong very fine subangular blocks; very hard, firm, sticky and very plastic; continuous clay films on peds; moderate effervescence; many fine and very fine roots; many fine and very fine pores; clear lower boundary.

B31Ca 14-22" Dark gray (10YR 4/1) clay, dark grayish-brown (10YR 4/2 rubbed and 3/2 unrubbed) moist; moderate medium and fine prisms that separate strong fine and very fine subangular blocks; very hard, firm, sticky and very plastic; few patches of clay films; medium effervescence; common prominent; medium and small masses of lime; many fine and very fine roots; many fine and very fine pores; gradual lower boundary.

B32Ca 22-38" Gray (10YR 5/1 marbeled with 5/3) clay, very dark grayish-brown (2.5Y 3/2 marbeled with 10YR 4/3) moist; strong medium prisms that separate to moderate medium subangular blocks; very hard, firm, sticky and very plastic; medium effervescence; common fine and very fine roots and many fine and very fine pores; gradual lower boundary.

Soil Description No. 2 (continued)

B33Ca 38-46" Gray (10YR 5/1 with mottles of 2.5Y 6/2) clay, very dark grayish-brown (2.5Y 3/2 with mottles of 5/2) moist; moderate coarse prisms that separate to moderate coarse subangular blocks; very hard, firm, sticky and very plastic; medium effervescence; few roots; many fine and very fine pores; clear lower boundary.

Ccs 46-66" Pale brown (10YR 6/3) silty clay loam, brown (10YR 5/3) moist; massive; hard, friable, sticky and very plastic; common distinct streaks of gypsum crystals.

Soil Description No. 3

KING INTERSEEDING EXCLOSURE

Soil Type: Abor silty clay.
Area: Petroleum County.
Date: November 25, 1970.
Classification: Fine montmorillonitic family of Borollic Vertic Camborthids.
Location: In NE¼NE¼ Section 19, T 14N, R26E.
Vegetation: Big sagebrush, blue grama, and western wheatgrass.
Parent Material: Silty clay shale.
Physiography: Upland.
Relief: Smooth undulating.
Elevation: 3100 feet.
Slope: 3 percent.
Aspect: Northwest.
Erosion: None.
Permeability: Slow.
Drainage: Well drained.
Gr. Water: Very deep.
Moisture: Dry.
Root distribution: Many to 11 inches -- common to 27 inches and few below.

Pedon Description: Abor silty clay.

A1 0-2"	Grayish-brown (2.5Y 5/2) silty clay loam, dark brown (10YR 3/3) moist; strong fine plates that separate to strong fine granules; soft; friable, sticky and plastic; no effervescence; many bleached silt and sand grains present; many fine roots; clear lower boundary.
B21 2-11"	Grayish-brown (2.5Y 5/2) silty clay, olive-brown (2.5Y 4/4) moist; moderate medium prisms that separate to strong fine subangular blocky structure; hard, friable, sticky and very plastic; moderate effervescence; many fine and very fine pores and roots; clear lower boundary.
B22 11-27"	Light brownish-gray (2.5Y 6/2) silty clay, grayish-brown (2.5Y 5/2) moist; moderate coarse prisms that separate moderate fine subangular blocks; very hard, firm, sticky and very plastic; distinct pressure faces; moderate effervescence; many fine and very fine pores; common fine and very fine roots; clear lower boundary.
C1 27-33"	Light brownish-gray (2.5Y 6/2) silty clay with many shale fragments; grayish-brown (2.5Y 5/2) moist; very weak medium subangular blocky structure; very hard, firm, sticky and very plastic; moderate effervescence; thin films of lime on underside of some shale fragments; few fine very fine roots and pores; gradual lower boundary.
C2Cs 36-65"	Light brownish-gray silty clay shale; moderate effervescence; streaks and pockets of gypsum crystals.

Soil Description No. 4

KING RIDGE EXCLOSURE (upper pit)

Soil Type: Bercail clay loam.
Date Described: August 12, 1970
Location: Petroleum County, Montana, NE¼, Section 19, T 14N, R26E.
Classification: Aridic Argiborolls, fine, montmorillonitic family.
Vegetation: Big sagebrush, bluebunch wheatgrass, prairie junegrass.
Parent Material: Clay-clay loam alluvium.
Physiographic Position: Footslope.
Relief: Smooth convex, sloping.
Slope: 6 percent.
Aspect: South.
Elevation: 3200 feet.
Drainage: Well drained.
Erosion: Slight.
Permeability: Moderately slow, 0.20 to 0.63"/hr.
Moisture: Dry.
Climate: Mean annual precipitation is 12 to 13 inches.
Mean annual temperature is about 44° F.
Frost-free period is 110 to 120 days.

Note: This soil differs from the typical Bercail soils in having an 8 to 10 percent increase in clay content in the 3 to 6-inch (B2t) horizon over that of the A horizon.

A1 0-3"	Grayish brown (10YR 5/2) clay loam, dark grayish brown (10YR 4/2) moist; moderate fine granular structure; hard, firm, sticky and plastic; bleached sand grain; abrupt boundary.
B2t 3-6"	Brown (10YR 5/3) clay, dark brown (10YR 4/3) moist; moderate medium prismatic structure; very hard, firm, sticky and very sticky; many micro roots and pores; thick continuous clay film; clear boundary.
B3ca 6-22"	Grayish brown (2.5Y 5/2) silty clay, dark grayish brown (2.5Y 4/2) moist; moderate medium prismatic structure; very hard, friable, sticky and plastic; strongly effervescent with common medium masses of lime segregation; many micro roots and pores; clear boundary.
B3 22-35"	Light yellowish brown (2.5Y 6/3) silty clay loam, grayish brown (2.5Y 5/2) moist; moderate medium prismatic structure; extremely hard, friable, sticky and plastic; strongly effervescent with few soft masses of lime segregation; many micro roots and pores; clear boundary.
IIc1 35-42"	Light olive brown (2.5Y 5/3) clay loam with few gravel, olive brown (2.5Y 4/3) moist; hard, friable, sticky and slightly plastic; strongly effervescent; few gypsum crystals; pH 9.0; few micro roots; gradul boundary.

Soil Description No. 4 (continued)

IIC2 42-60"	Light yellowish brown (2.5Y 6/3) silty clay loam with few gravel, light olive brown (2.5Y 5/3) moist; massive; hard, friable, sticky and plastic; strongly effervescent; common micro roots; common streaks of gypsum.

Soil Description No. 4

KING RIDGE EXCLOSURE (lower pit)

Soil Type: Bercail clay loam.
Date Described: August 12, 1970 by EKH.
Location: NE¼, Sec. 19, T 14N, R26E -- Petroleum County, Montana. This soil is described in the lower pit.
Classification: Aridic Argiborolls -- fine montmorillonitic family.
Vegetation: Big sagebrush, bluebunch wheatgrass, prairie junegrass.
Parent Material: Light clay, local alluvium.
Physiographic Position: Fan.
Relief: Smooth, convex.
Elevation: 3200 feet.
Slope: 5 percent.
Aspect: South.
Drainage: Well drained.
Erosion: Slight.
Permeability: Slow or moderately slow.
Moisture: Dry.
Climate: Cool, semiarid -- about 13 inches annual precipitation. Frost-free period, 110-120 days.
Roots: Many micro roots to 30 inches, common micro roots to 47 inches, few below.

Note: This soil differs from the typical Bercail soils in having a 10 percent increase in clay content in the 2 to 8-inch (B2t) horizon over that of the A horizon.

A1 0-2" Grayish brown (10YR 5/2) clay loam, dark grayish brown (10YR 4/2) moist.

B2t 2-8" Brown (10YR 5/3) clay, brown (10YR 4/3) moist; strong medium prismatic breaking to strong medium and fine subangular blocky; very hard when dry, firm when moist, sticky and very plastic; many micro roots and pores; noncalcareous, pH 8.0, abrupt boundary.

B3cs 8-22" Gray (10YR 5/1) clay, dark gray (10YR 4/1) moist; moderate medium prismatic structure separating to strong medium subangular blocky; very hard, friable, sticky and plastic; calcareous; common masses of lime; pH 8.4; many micro roots and pores, clear boundary.

IIc1 22-30" Light yellowish brown (2.5Y 6/3) sandy clay loam, light olive brown (2.5Y 5/3) moist; moderate medium blocky; very hard, friable, plastic and sticky; calcareous; pH 8.4; many micro roots and pores.

IIIC2 30-47" Light yellowish brown (2.5Y 6/3) clay, light olive brown (2.5Y 5/3) moist; weak coarse prismatic structure; very hard, firm,

Soil Description No. 4 (continued)

IIIC2 30-47" continued.

sticky and plastic; strongly calcareous; pH 8.8; many micro roots and common micro pores, clear boundary.

IIIC3 47-60" Light yellowish brown (2.5Y 6/3) clay, light olive brown (2.5Y 5/3) moist; massive, friable, sticky and plastic calcareous; common masses of gypsum; pH 8.4.

Soil Description No. 5

WINNETT EAST

Soil Type: Marias silty clay.
Area: Petroleum County.
Date: November 24, 1969.
Classification: Fine montmorillonitic family of Ustollic Camborthids.
Location: In NE¼SE¼ Section 22, T 15N, R26E.
Vegetation: Big sagebrush and western wheatgrass.
Parent Material: Clayey alluvium.
Physiography: Mantled upland.
Relief: Smooth.
Elevation: 3100 feet.
Slope: 2 percent.
Aspect: Southeast.
Erosion: None.
Permeability: Slow.
Drainage: Well drained.
Gr. Water: Very deep.
Moisture: Dry to 25 inches -- slightly moist below.
Root distribution: Many fine and very fine to 22 inches -- few below.

Pedon Description: Marias silty clay.

A1 0-3"	Grayish-brown (2.5Y 5/2) silty clay, dark grayish-brown (2.5Y 4/2) moist; strong fine granular structure; friable, sticky and very plastic; many fine roots; weak effervescence; clear lower boundary.
B21 3-12"	Grayish-brown (2.5Y 5/2) clay, dark grayish-brown (2.5Y 4/2) moist; moderate coarse prisms that separate to weak, coarse, subangular blocks; extremely hard, firm, sticky and very plastic; medium effervescence; slight pressure faces; many fine and very fine pores and roots; gradual lower boundary.
B22 12-25"	Grayish-brown (2.5Y 5/2) clay, dark grayish-brown (2.5Y 4/2) moist; moderate coarse subangular blocky structure; extremely hard, firm, sticky and very plastic; distinct pressure faces; many fine and very fine pores; common fine and very fine roots; clear lower boundary.
B3Ca 25-24"	Grayish-brown (2.5Y 5/2) clay with 5 percent gravels, dark grayish-brown (2.5Y 4/2) moist; moderate medium and fine subangular blocky structure; extremely hard, firm, sticky and very plastic; medium effervescence; common fine and very fine pores; few roots; abrupt lower boundary.
C1Cs 34-60"	Grayish-brown (2.5Y 5/2 unrubbed and 5/1 rubbed) clay, dark grayish-brown (2.5Y 4/2 unrubbed and 4/1 rubbed) moist; massive; very hard, firm, sticky and very plastic; medium effervescence; many prominant streaks and threads of gypsum with some lime; few very fine roots and pores.

Soil Description No. 6

WINNETT EXCLOSURE

Soil Type: Thebo clay.
Area: Petroleum County.
Date: November 24, 1969.
Classification: Very fine, montmorillonitic, frigid family of Entic Chromoxererts.
Locations: In enclosure in NE¼NE¼, Section 21, T 15N, R26E.
Native vegetation: Big sagebrush, blue grama, thickspike wheatgrass and prairie junegrass.
Parent material: Clay weathered in place from clay shale.
Physiography: Upland
Relief: Gentley undulating.
Elevation: 3100 feet.
Slope: 3 percent.
Aspect: Southwest.
Erosion: Slight.
Permeability: Very slow.
Drainage: Well drained.
Gr. Water: Very deep.
Moisture: Dry to 20 inches and slightly moist below.
Root distribution: Many to 12 inches, common to 15 inches-few below.

Additional Notes: This soil differs from the typical Thebo series in having a 2½-inch clay loam surface horizon with an abundance of bleached silt and sand, rather than a granular clay without bleached silt and sand.

Pedon Description: Thebo Clay.

A1 0-2" Light brownish-gray (2.5Y 6/2) clay loam with an abundance of bleached silt and sand, dark grayish-brown (2.5Y 4/2) moist; moderate fine platy structure; slightly hard, friable, sticky and plastic; abrupt lower boundary.

B2 2-11" Grayish-brown (2.5Y 5/2) clay, dark grayish-brown (2.5Y 4/2) moist; weak medium and coarse prisms that separate to medium and coarse subangular blocks; distinct horizontal pressure faces present; extremely hard, firm, sticky and very plastic; common very fine pores and many fine roots; clear lower boundary.

C1 11-15" Grayish-brown (2.5Y 5/2) clay, dark grayish-brown (2.5Y 4/2) moist; moderate medium blocky structure; distinct pressure faces; extremely hard, firm, sticky and very plastic; weak effervescence; common very fine pores; common fine roots; clear lower boundary.

C2CaCs 15-27" Grayish-brown (2.5Y 5/2 unrubbed and 10YR 4/1 rubbed) clay, dark grayish-brown (1.5Y 4/2 unrubbed and 10 YR 3/1 rubbed) moist; massive; extremely hard, firm, sticky and very plastic; moderate effervescence; many medium threads of fine gypsum crystals; few fine pores: common fine roots; gradual lower boundary.

Soil Description No. 6 (continued)

C3Cs 27-46"	Same colors as above horizon; weathered shale that rubs to clay; noncalcareous; few fine roots and pores; common medium clusters of gypsum crystals; gradual lower boundary.
C4Cs 46-60"	Noncalcareous clay shale with common streaks and clusters of gypsum crystals.

Soil Description No. 7

WINNETT STRIP WEST

Soil Type: Syblon silt loam.
Area: Petroleum County.
Date: November 24, 1969.
Classification: Fine, mixed, frigid family of Borollic Paleargids.
Location: In NW¼NE¼, Section 20, T 15N, R26E.
Vegetation: Big sagebrush, blue grama, bluebunch wheatgrass, and prairie junegrass.
Parent Material: Silty clay loam weathered from underlying shale and sandstone.
Physiography: Upland.
Relief: Smooth -- gently undulating.
Elevation: 3100 feet.
Slope: 3 percent.
Aspect: East.
Erosion: None to slight.
Permeability: Moderate.
Drainage: Well drained.
Gr. Water: More than 6 feet.
Moisture: Dry throughout.
Root distribution: Many to 12 inches -- common to 28, few below.

Additional Notes: Pockets of calcareous rock in places at depths of 5 to 14 inches.

Pedon Description: Syblon silt loam.

A1 0-5" Grayish-brown (1 YR 5/2) silt loam, dark grayish-brown (1YR 4/2) moist; weak fine plates that separate to fine granules; slightly hard, very friable, nonsticky and nonplastic; many bleached silt and sand grains; many fine roots; abrupt lower boundary.

B2t 5-12" Grayish-brown (10YR 5/2) silty clay (40 percent clay, absolute) dark grayish-brown (10YR 4/2 unrubbed and 2.5Y 4/2 rubbed) moist; strong medium prisms that separate to very fine subangular blocks; hard, friable, sticky and plastic; many fine roots and many fine and very fine pores; clear lower boundary.

C1 12-19" Grayish-brown (2.5Y 5/2 unrubbed and 10YR 5/1 rubbed) silty clay loam (35 percent clay, absolute) dark grayish-brown (2.5Y 4/2 unrubbed and 10YR 4/1 rubbed) moist; moderate medium and fine platey structure; hard, friable, sticky and plastic; weak effervescence; few thin films of lime; common fine roots; common fine and very fine pores; gradual lower boundary.

C2ca 19-28" Grayish-brown (2.5Y 5/2 unrubbed and 10YR 5/1 rubbed) clay loam with shale chips and sandstone fragments, dark grayish-brown (2.5Y 4/2 unrubbed and 10YR 4/1 rubbed) moist; strong effervescence; sandstone fragments undercoated with lime; common fine roots; no pores; gradual lower boundary.

C3 28-53" Interbedded gray shale and weathered silt stone; few fine roots.

Soil Description No. 8

AGROPYRON SPICATUM EXCLOSURE (Iverson)

Soil Type: Verson clay loam, thin solum variant.
Date Described: August 12, 1970 by EKH.
Location: SE¼SE¼, Section 13, T 12E, R25E -- Petroleum County.
Classification: Aridic Argiborolls -- fine montmorillonitic family.
Vegetation: Bluebunch wheatgrass, prairie junegrass, big sagebrush.
Parent Material: Light clay over very gravelly loam alluvium.
Physiographic Position: Bench.
Relief: Smooth.
Elevation: 3300 feet.
Drainage: Well drained.
Erosion: None.
Permeability: Moderately slow.
Moisture: Dry.
Climate: Cool, semi-arid; 13 inches annual precipitation.

Note: This pit is located on a slightly convex area. The B2t horizon is thinner than the soil on the west end of the enclosure.

A1 0-2" Grayish-brown (2.5Y 5/2) loam, very dark grayish-brown (10YR 3/2) when moist; weak fine plates separating to strong very fine granular structure; slightly hard, friable, and slightly sticky; bleached sand grains; abrupt boundary.

B2t 2-6" Dark grayish-brown (10YR 4/2) clay, very dark grayish-brown (10YR 3/2) moist; moderate medium prismatic separating to strong medium subangular blocky; hard, friable, sticky and very plastic; many micro roots and pores; thick continuous clay films; weakly calcareous in lower part; clear boundary.

B3 6-18" Grayish-brown (2.5Y 5/2) silty clay, dark grayish-brown (2.5Y 4/2) moist; grayish-brown (2.5Y 5/2) dry; moderate medium prismatic separating to moderate medium and fine subangular blocky; hard, friable, sticky and very plastic; calcareous; many fine threads of lime; many micro roots and pores; patchy clay film; clear boundary.

B3ca 18-25: Grayish-brown (2.5Y 5/2) silty clay, dark grayish-brown (2.5Y 4/2) moist; moderate medium prismatic separating to moderate medium and fine subangular blocky structure; hard, friable, sticky and plastic; calcareous; common masses of lime, abrupt boundary.

IIc1 25-40" Pale brown (10YR 6/3) very gravelly loam, brown (10YR 4/3) moist; very friable; nonplastic nonsticky; many micro roots to 30 inches; common micro roots below 30 inches.